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STAGE 1 PROPELLANT, SURVEILLANCE REPORT, GLACIAL ACRYLIC ACID, --ETC(U)
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OGDEN AIR LOGISTICS CENTER
UNITED STATES AIR FORCE
HILL AIR FORCE BASE, UTAH 84056

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STAGE I PROPELLANT SURVEILLANCE REPORT GLACIAL ACRYLIC ACID MOTORS GAA-001 AND GAA-002 TP-H1011

PROPELLANT ANALYSIS LABORATORY

MAKPH REPORT
NR 441(80)

MAY 1980

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MAKPH REPORT NR 441(80)

PROPELLANT SURVEILLANCE REPORT

PROPELLANT CONTAINING GLACIAL ACRYLIC ACID

MOTORS GAA-001 and GAA-002

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ABSTRACT

Thiokol Minuteman First Stage Propellant used acrylic acid to produce the HB polymer used as the binder. The original supplier of acrylic acid stopped production and Thiokol then obtained acrylic acid produced by the Taft, Louisiana Plant of Union Carbide Company (UCC).

To assure that this new source of supply was a satisfactory replacement, Thiokol* ran qualification testing on the new material and found it satisfactory. In the Thiokol* program two motors were cast in 1971 and propellant from the mixes were cast into cartons for a ten year test program. This propellant was then transferred to this laboratory and testing on a yearly basis was started in 1975.

From an analysis of the data the propellants physical properties are satisfactory and the stability, with respect to age, is satisfactory.

*Final report evaluation of HB polymer manufactured using Taft glacial acrylic acid. Report number TWR-4716, May 1972. Thiokol/Wasatch Division, a division of Thiokol Chemical Corporation.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont)

INTRODUCTION

A. PURPOSE:

The purpose of this report is to compare physical data from glacial acrylic acid propellant used in the production of motors GAA-001 and GAA-002 with LGM-30F & G (TP-H1011) propellant data, and to assure that the modulus from the low rate testing is at least 550 psi @ 2.0 in/min and 77°F, and to evaluate the data to assure satisfactory propellant performance now and in the future.

B. BACKGROUND

Minuteman Stage I rocket motors used TP-H1011 type propellant in the main grain. The binder system used in these propellants consists of controlled amounts of HB polymer and epoxy resin. The ratio of HB polymer/epoxy resin depends on stoichiometry of the polymers and also on the type and amount of impurities contained in the polymer. From past experience, the propellant mechanical and ballistic properties have been influenced by these impurities. Many impurities have been traced to the original raw materials, especially to the acrylic acid monomers. Aqueous acrylic acid is a product of the Institute, West Virginia, Union Carbide Company (UCC) plant and was used for eight years. UCC then announced that aqueous acid production had stopped and a monomer, glacial acrylic acid was being produced in their Taft, Louisiana plant.

This change necessitated the selection and verification of a new monomer.

This required: (1) preliminary evaluation of polymers made from existing glacial acids, (2) detailed evaluation of an immediately available acid source, (3) screening of polymers made using glacial acid from the candidate vendors including the new Taft material, and (4) final verification of the selected material,

The HB polymer, made from Taft glacial acrylic acid monomer, produced propellant that met the requirements of the verification program.

Two full scale motors were cast using glacial acrylic acid HB polymer (Motors GAA-001 & GAA-002). Forty-six one-half gallon cartons of propellant were cast in conjunction with these motors on 12-14 Jan 1971. Table 1 contains the test methods used for test period.

Regressions were plotted using the acrylic acid test data. These regressions are discussed and compared statistically to LGM-30 F & G regressions. The LGM-30 F & G regressions are included with the respective acrylic acid regressions for visual inspection. The modulus requirement for the 2.0 in/min at 77° F test data is discussed in the low rate tensile testing section.

It should be noted that in the discussion of test results it is often stated that test points are within a particular confidence band on the regression analysis. The word point refers to the mean of a particular group of data. The individual data that were used to comprise that mean are of course grouped around the mean. The standard deviation associated with each mean can be used to estimate where the extreme data spread would be with relation to the confidence bands.

STATISTICAL ANALYSIS

Regression analysis data pertaining to propellant having glacial acrylic acid used in its manufacture has been statistically compared to regression data pertaining to standard TP-H1011 F and G propellant. Table 2. contains the results obtained in comparing 18 sets of regression slopes. Those comparisons that showed their slopes to be not significantly different were again compared to determine whether their intercepts (or elevations) were different, see Table 3. Only cohesive energy, a tear energy parameter, was found to be the same in slope and intercept to that of standard TP-H1011 F and G propellant.

Acrylic acid regression plots were made for each test parameter and can be visually compared to their corresponding standard TP-H1011 F and G plots. Emphasis is made here that the differences obtained are of statistical nature and may or may not be significant in an engineering sense.

Each regression analysis in this report uses the linear model $Y = a + bX$. Each point (x) on a regression plot represents a data mean at its particular age at test. Variance about each regression line was used to compute a tolerance interval such that at 90% confidence 90% of the sample distribution will fall within this interval. This tolerance interval is extrapolated 24 months beyond the age of the last test data. The 't' value and the significance of this statistic, which are reported for each regression model, give an indication of the statistical significance of the slope of the trend line as compared to a line of zero slope.

TEST RESULTS

A. VERY LOW RATE TENSILE (0.002 in/min):

Very low rate regressions show no significant change for maximum stress. The stress at rupture and strain at maximum stress shows a statistically significant increase with the strain at rupture and modulus showing no significant change (figures 1, 3, 5, 7 and 9). The respective LGM-30 F & G regressions are shown for visual comparison (figures 2, 4, 6, 8 and 10). Comparison of the slopes with the respective F and G slopes show no significant difference for the stresses with a statistically significant increase in the slopes for the strain data (Table 2). The regression slope intercepts for the stresses show a statistically significant difference when compared to LGM-30 F & G intercepts (Table 3).

B. LOW RATE TENSILE (2.0 in/min):

The maximum stress regression shows no significant change and the stress at rupture shows a statistically significant increase (figures 11 and 13). The strains and modulus regressions do not show a significant change (figures 15, 17 and 19). The respective LGM-30 F & G regressions are shown for a visual comparison (figures 12, 14, 16, 18 and 20). The stresses are less and the strains are greater than for the respective LGM-30 propellant.

Comparison of the slopes with the respective F & G slopes shows no difference for maximum stress, strain at rupture and modulus with a statistically significant difference for stress at rupture and strain at maximum stress (Table 2). The regression slope intercepts for max-

imum stress, strain at rupture and modulus show a statistically significant difference. As seen in the regression for modulus (figure 19), all of the test data is well above the minimum requirement of 550 psi at 2.0 in/min and 77°F.

C. HIGH RATE HYDROSTATIC TENSILE (1750 in/min, 800 psi):

The stresses and modulus show a statistically significant increase (figures 21, 23 and 29). The strains show a statistically significant decrease (figures 25 and 27). F & G regressions (figures 22, 24, 26, 28 and 30) are included for visual comparison with the respective Acrylic Acid regressions. Comparison of the slopes with the respective F & G slopes show significantly different trends for all the regressions, except for strain at rupture (Table 2). A comparison of the intercepts for strain at rupture shows a statistically significant difference (Table 3).

D. CONSTANT STRAIN:

The constant strain at rupture regression shows a statistically significant decrease (figure 31). The F & G regression (figure 32) is included for a visual comparison.

A comparison of the regression slope with the respective F & G slope shows a statistically significant difference (Table 2).

E. TEAR ENERGY:

Tear energy does not show a significant change (figure 33) with the time to tear showing a statistically significant increase (figure 35). F & G regressions (figures 34 and 36) are included for visual comparison with the respective acrylic acid regressions.

Comparison of the slopes with the respective F & G slopes show that the cohesive energy is not significantly different while the time to tear is significantly different (Table 2). Cohesive energy intercepts are not significantly different (Table 3).

CONCLUSIONS

The testing data shows this propellant and LGM-30 propellant data to be in good agreement as to the physical properties and aging trends. The modulus is well above the Thiokol requirement of at least a 550 psi modulus @ 2.0 in/min and 77°F test conditions.

From this analysis may be concluded that the propellant produced with glacial acrylic acid is performing satisfactory at this time.

RECOMMENDATIONS

It is recommended that testing be continued as planned.

TABLE 1

TEST PROGRAM

Half gallon cartons of propellant were cast from the same mixes that went into the full scale motors. These were cast and labelled for the repsective motors and from these cartons, specimens were cut for the tests and conditions listed below:

Test	Condition	Configuration	Per Cond
Low Rate Tensile	2.0 in/min	1/2" JANNAF Dog Bone	12
Very Low Rate Tensile	2×10^{-3} in/min	1/2" JANNAF Dog Bone	12
Constant Strain		JANNAF Dog Bone	12
Hydrostatic High Rate Tensile	800 psig, 1750 in/min	3/4" GL Dog Bone	12
Tear Energy	77°F ± 2°	0.10" x 1.18" x 3"	12

TABLE 2

REGRESSION SLOPE COMPARISONS

	DF	t	SIG
Tensile at 0.002 in/min			
Maximum Stress	18286	1.04	NS
Stress at Rupture	17814	0.86	NS
Strain at Max Stress	18286	4.30	S
Strain at Rupture	18286	3.23	S
Modulus	18312	2.90	S
Tensile at 2.0 in/min			
Maximum Stress	16191	0.19	NS
Stress at Rupture	16186	3.08	S
Strain at Max Stress	16190	2.43	S
Strain at Rupture	16187	1.49	NS
Modulus	16182	0.48	NS
Hydrostatic Tensile at 1750 in/min			
Maximum Stress	3834	12.41	S
Stress at Rupture	3834	12.42	S
Strain at Max Stress	3829	3.45	S
Strain at Rupture	3832	1.04	NS
Modulus	3833	3.68	S
Constant Strain			
Strain at Rupture	5658	2.79	S
Tear Energy			
Cohesive Energy	228	0.82	NS
Time to Tear	228	11.55	S

DF = Degrees of Freedom
S = Significantly Different
NS = Not Significant

TABLE 3

COMPARISON OF INTERCEPTS

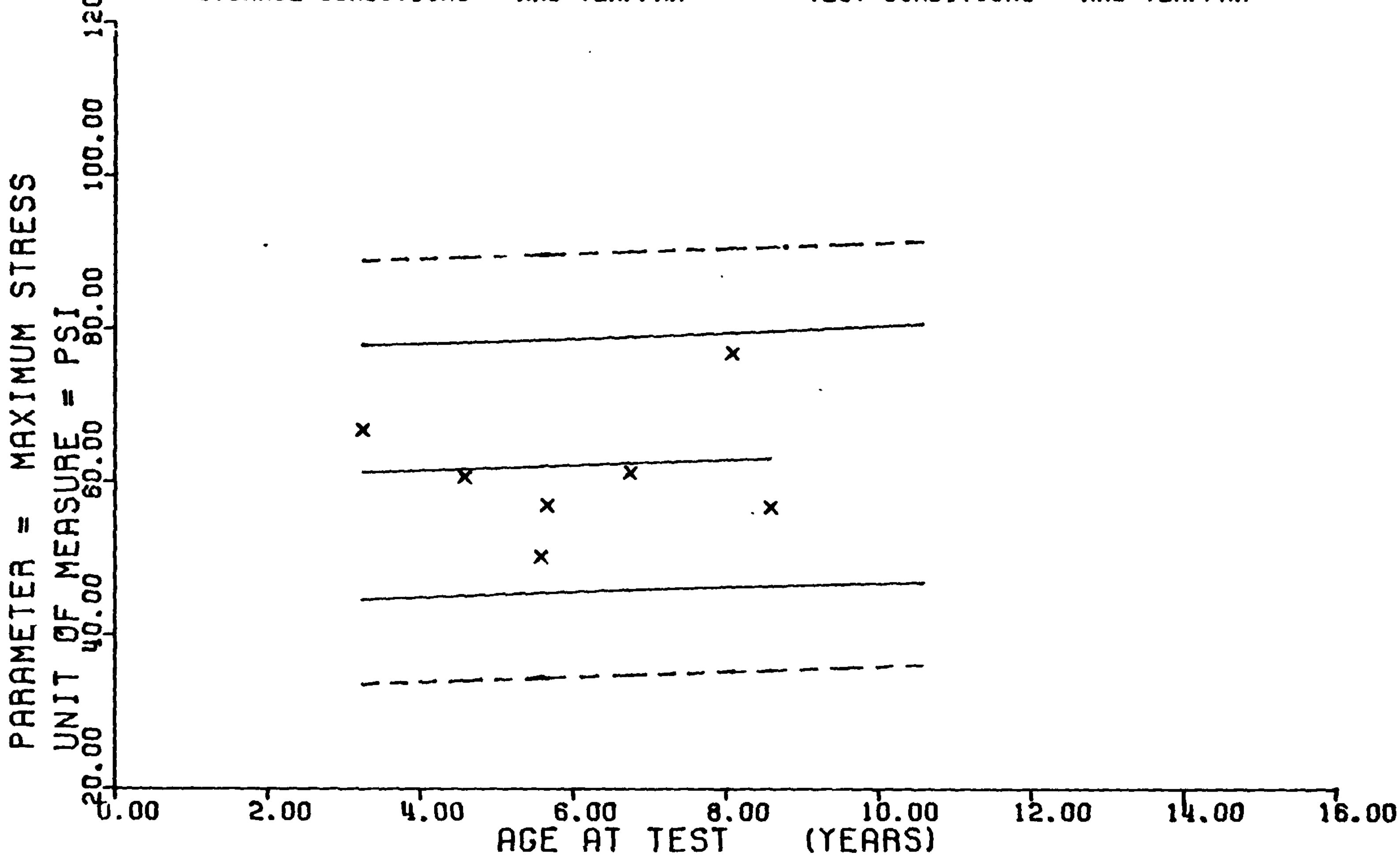
	DF	t	SIG
Tensile at 0.002 in/min			
Maximum Stress	144	6.35	S
Stress at Rupture	144	8.28	S
Tensile at 2.0 in/min			
Maximum Stress	119	5.86	S
Strain at Rupture	119	3.14	S
Modulus	119	2.61	S
Hydrostatic Tensile at 175° in/min			
Strain at Rupture	113	2.65	S
Tear Energy			
Cohesive Energy	99	0.71	NS

DF = Degrees of Freedom
S = Significantly Different
NS = Not Significant

Y = ((+6.0068341E+01) + (+2.9114104E-02) * X)

F = +7.1521084E-01 SIGNIFICANCE OF F = NOT SIGNIFICANT σ_Y = +9.2053793E+00
R = +7.0300749E-02 SIGNIFICANCE OF R = NOT SIGNIFICANT S_b = +3.4425986E-02
t = +8.4570139E-01 SIGNIFICANCE OF t = NOT SIGNIFICANT S_t = +9.2144326E+00
N = 146 DEGREES OF FREEDOM = 144

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



TENSILE, MAXIMUM STRESS AT 0.002 IN/MIN, ACRYLIC ACID STUDY

Figure 1

Y = ((+7.5926403E+01) + (+5.4051640E-02) * X)

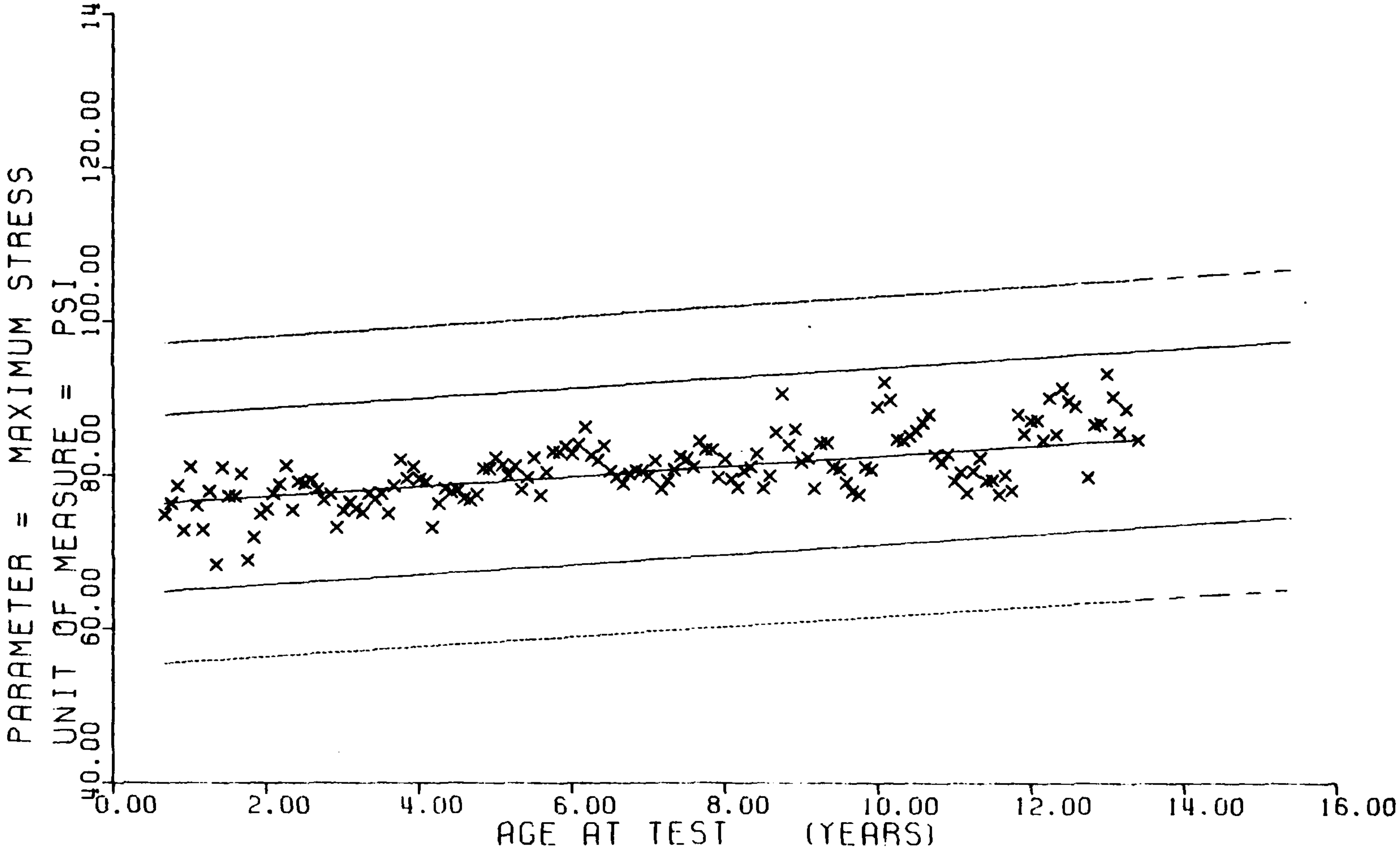
F = +1.2956320E+03 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +7.1835107E+00

R = +2.5817795E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +1.5016476E-03

t = +3.5994888E+01 SIGNIFICANCE OF t = SIGNIFICANT S_E = +6.9401621E+00

N = 18144 DEGREES OF FREEDOM = 18142

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



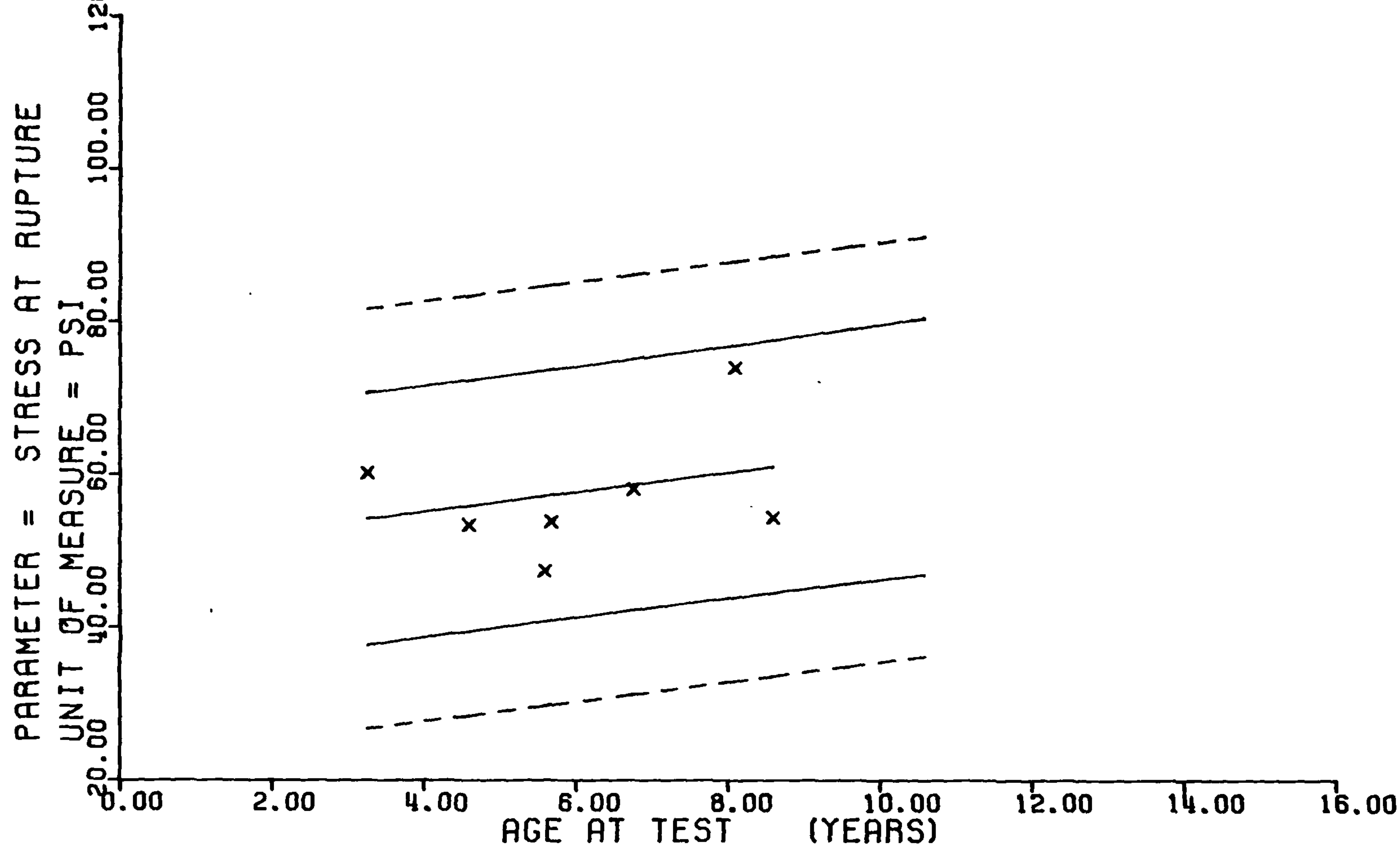
WING 6,V.L.R.TENSILE,MAXIMUM STRESS,CHS=0.002 IN/MIN TP-H1011

Figure 2

$Y = ((+4.9983104E+01) + (+1.0750190E-01) * X)$

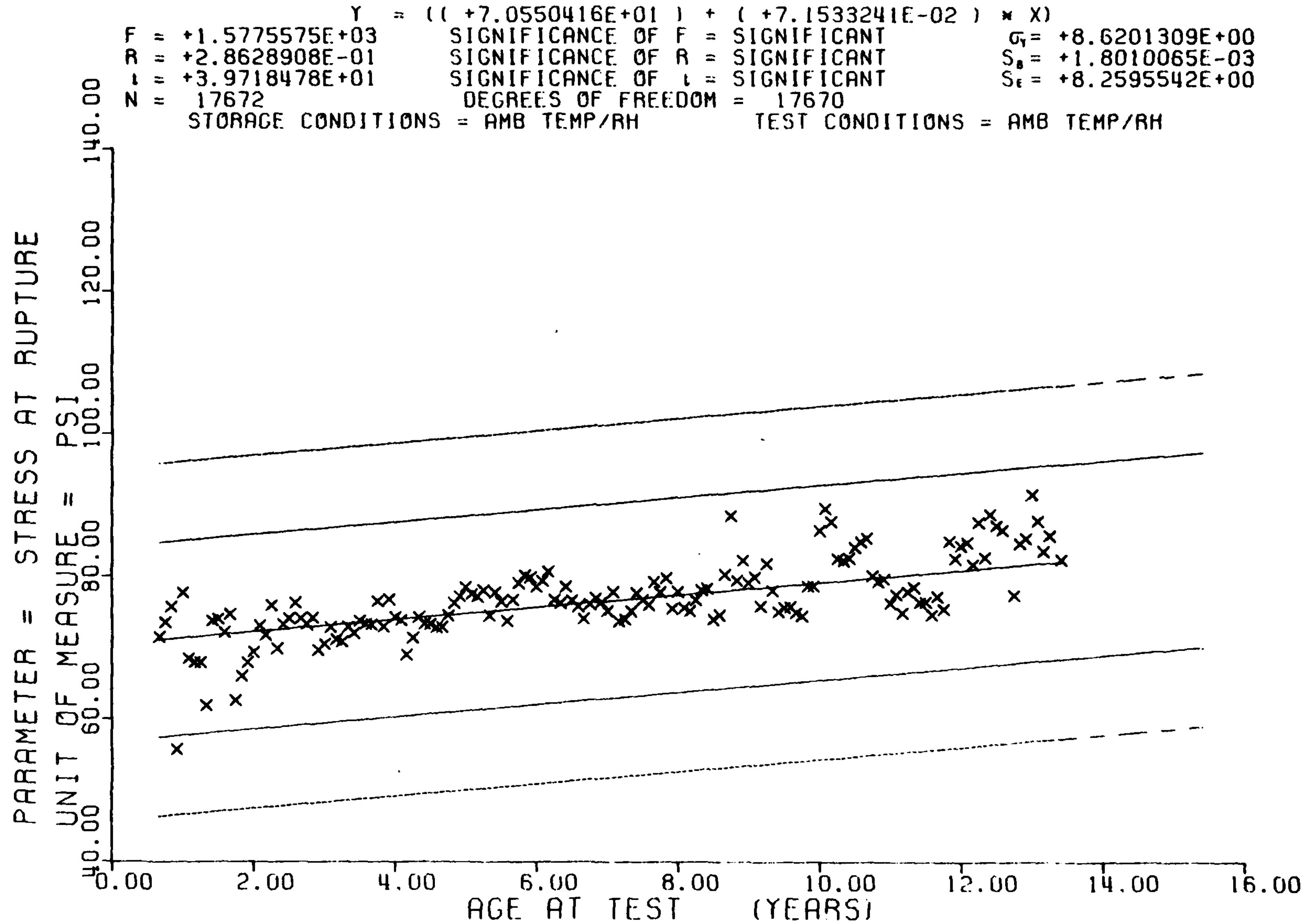
F = +9.8723631E+00	SIGNIFICANCE OF F = SIGNIFICANT	σ_Y = +9.4337446E+00
R = +2.5329711E-01	SIGNIFICANCE OF R = SIGNIFICANT	S_β = +3.4214137E-02
t = +3.1420316E+00	SIGNIFICANCE OF t = SIGNIFICANT	S_ε = +9.1577294E+00
N = 146	DEGREES OF FREEDOM = 144	

STORAGE CONDITIONS = AMB TEMP/AH TEST CONDITIONS = AMB TEMP/AH



TENSILE, STRESS AT RUPTURE, 0.002 IN/MIN, ACRYLIC ACID STUDY

Figure 3



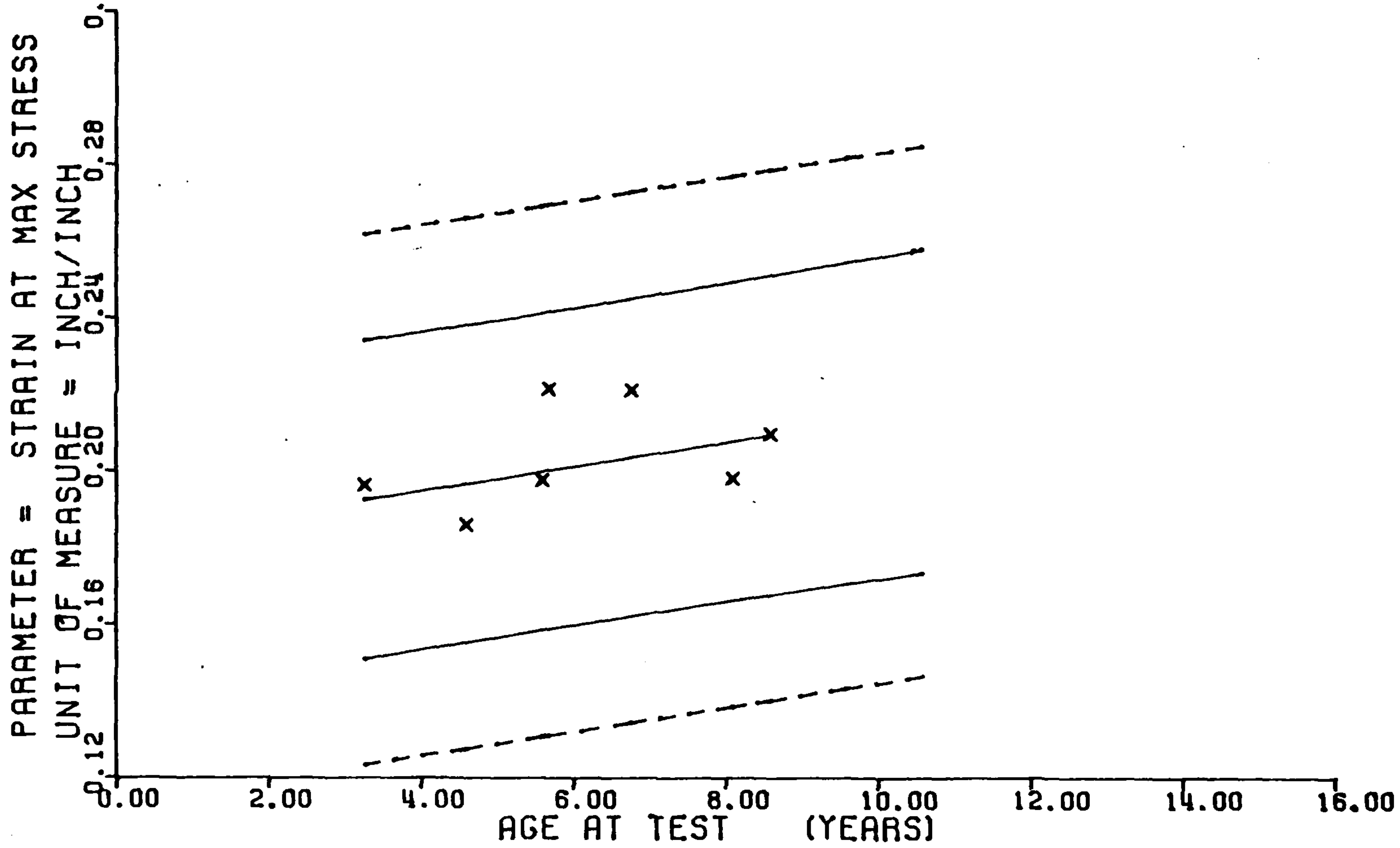
WING 6,V.L.R.TENSILE,STRESS AT RUPTURE,CHS=0.002 IN/MIN TP-H1011

Figure 4

Y = ((+1.8224308E-01) + (+2.6359494E-04) * X)

F = +9.3256959E+00 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +2.3757576E-02
R = +2.4662276E-01 SIGNIFICANCE OF R = SIGNIFICANT S_b = +8.6317023E-05
t = +3.0538002E+00 SIGNIFICANCE OF t = SIGNIFICANT S_E = +2.3103547E-02
N = 146 DEGREES OF FREEDOM = 144

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



TENSILE, STRAIN AT MAX STRESS, 0.002 IN/MIN, ACRYLIC ACID STUDY

Figure 5

Y = ((+2.0572913E-01) + (-4.6394204E-06) * X)

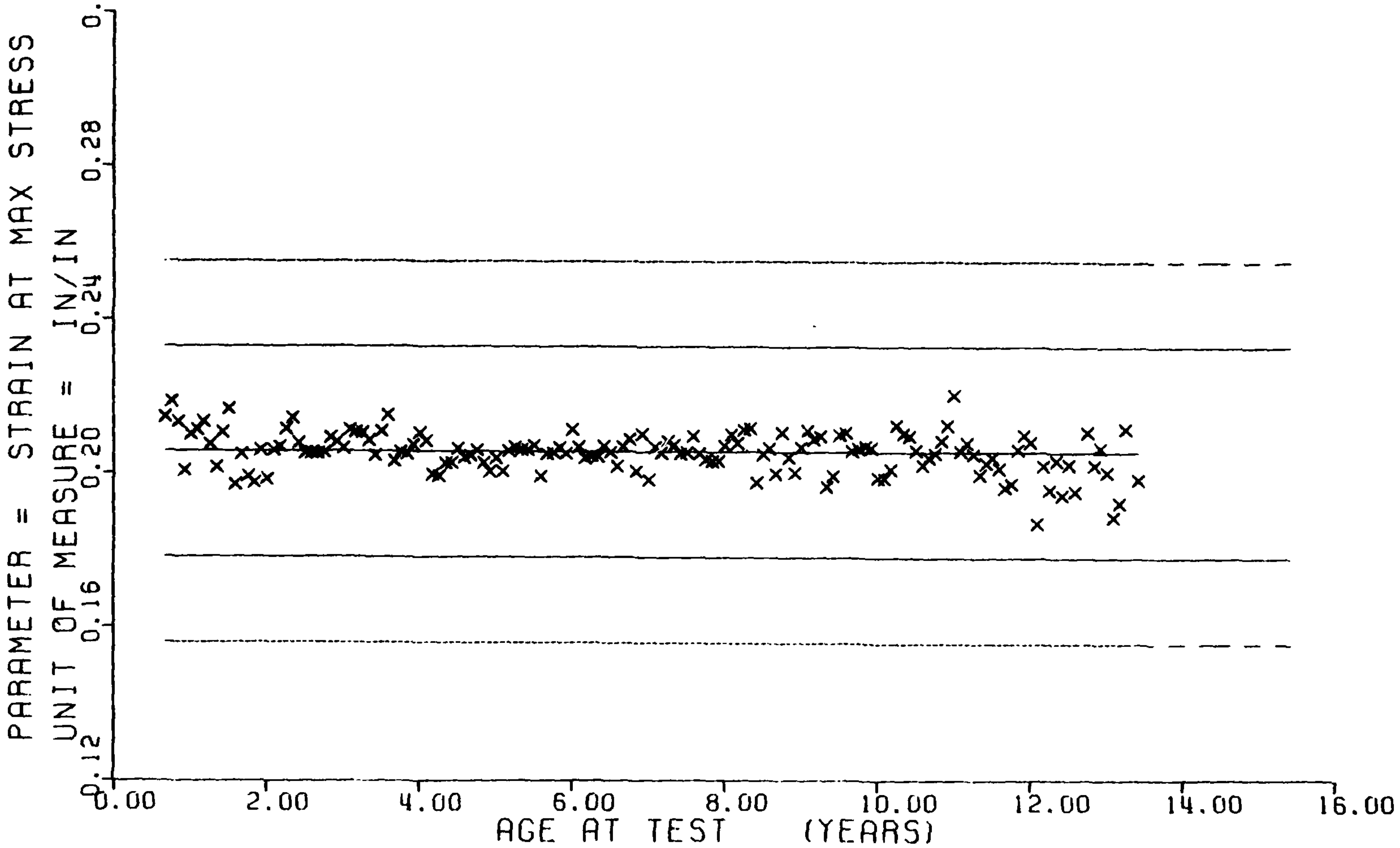
F = +1.6799896E+00   SIGNIFICANCE OF F = NOT SIGNIFICANT σ_Y = +1.6542718E-02

R = -9.6228249E-03   SIGNIFICANCE OF R = NOT SIGNIFICANT S_B = +3.5794016E-06

ι = +1.2961441E+00   SIGNIFICANCE OF ι = NOT SIGNIFICANT S_ϵ = +1.6542408E-02

N = 18143   DEGREES OF FREEDOM = 18141

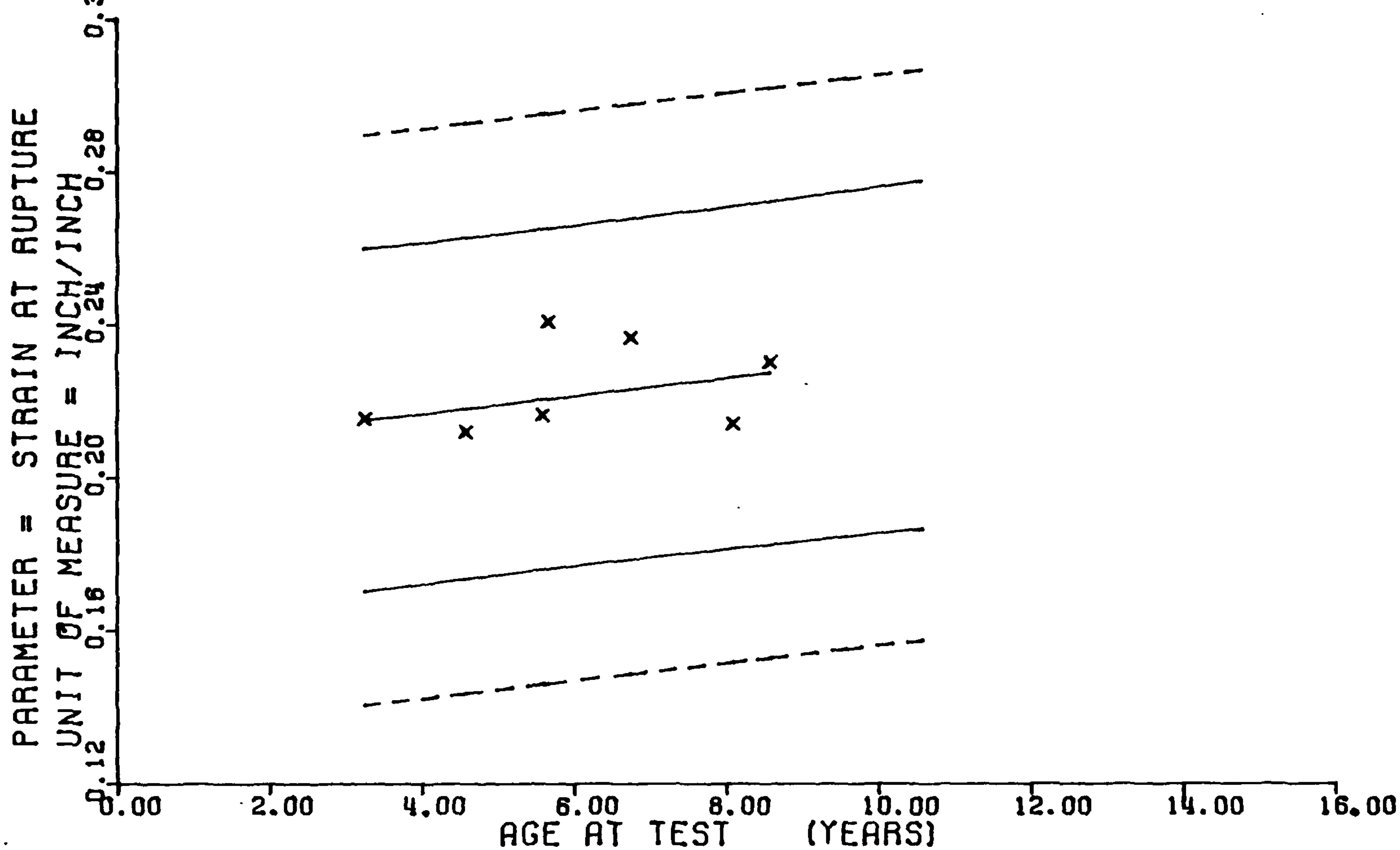
STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH



WING 6,V.L.R.TENSILE,STRAIN AT MAX STRESS,CHS=0.002 IN/MIN TF-H1011

Figure 6

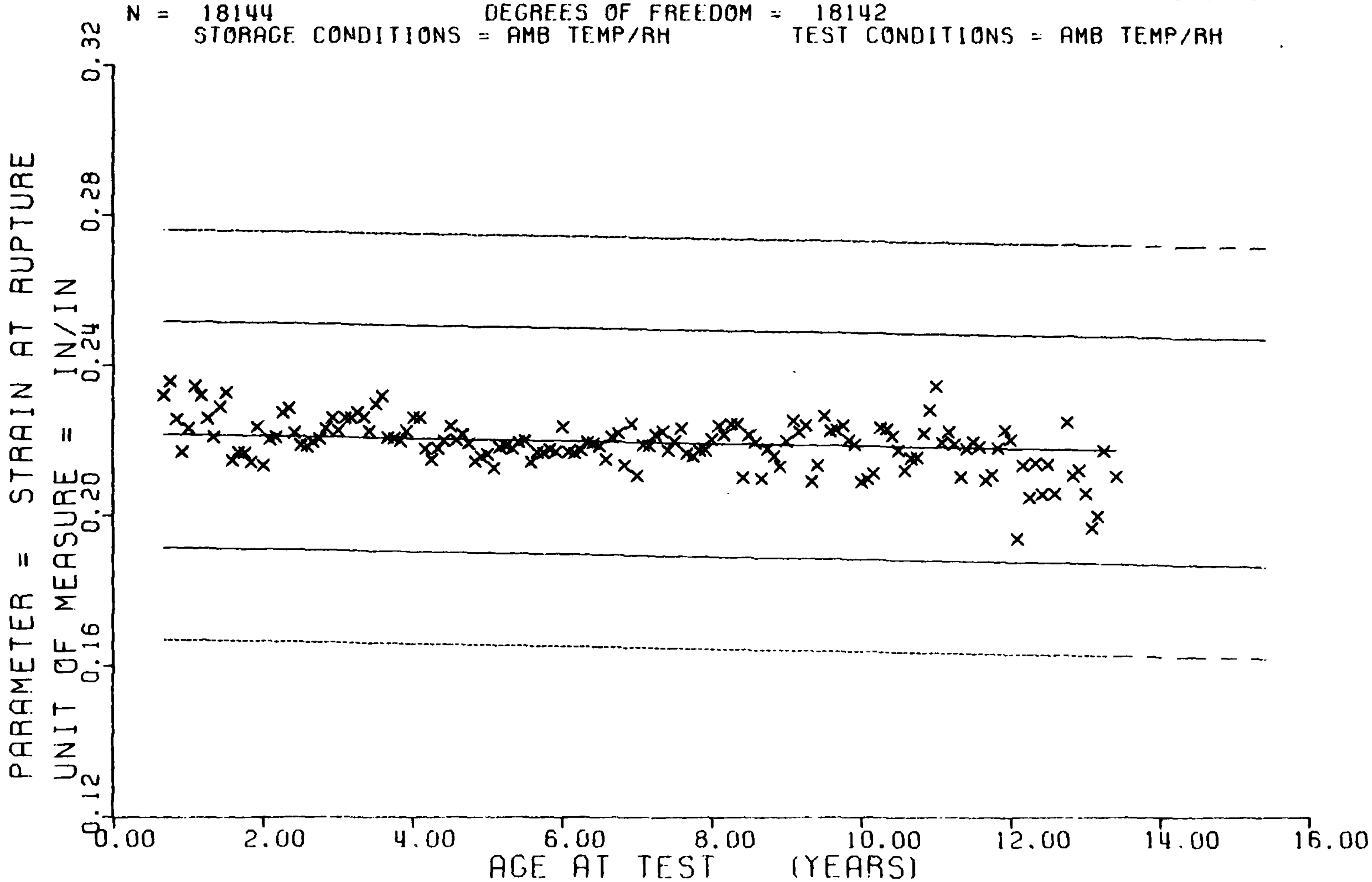
Y = ((+2.0755848E-01) + (+1.9245332E-04) * X)
F = +4.2938193E+00   SIGNIFICANCE OF F = NOT SIGNIFICANT   σ = +2.5139884E-02
R = +1.7016112E-01   SIGNIFICANCE OF R = SIGNIFICANT S_a = +9.2876007E-05
t = +2.0721533E+00   SIGNIFICANCE OF t = SIGNIFICANT S_t = +2.4859119E-02
N = 146   DEGREES OF FREEDOM = 144
STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH



TENSILE, STRAIN AT RUPTURE, 0.002 IN/MIN, ACRYLIC ACID STUDY

Figure 7

Y = ((+2.2201304E-01) + (-2.8955103E-05) * X)
F = +5.4211634E+01 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +1.8201888E-02
R = -5.4582794E-02 SIGNIFICANCE OF R = SIGNIFICANT S_B = +3.9325917E-06
t = +7.3628550E+00 SIGNIFICANCE OF t = SIGNIFICANT S_E = +1.8175254E-02
N = 18144 DEGREES OF FREEDOM = 18142
STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



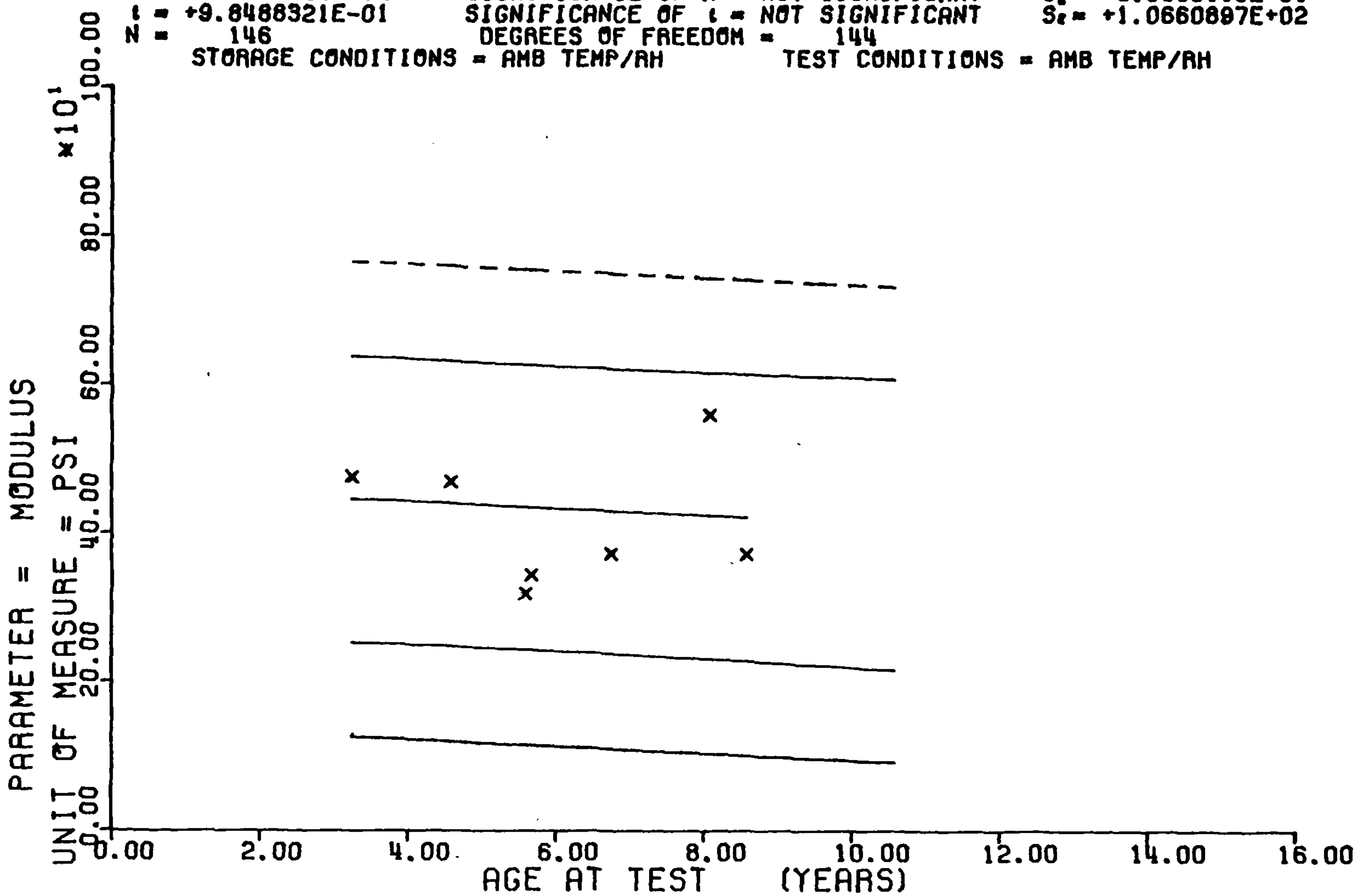
WING 6,V.L.R.TENSILE,STRAIN AT RUPTURE,CHS=0.002 IN/MIN TP-H1011

Figure 8

Y = ((+4.6140900E+02) + (-3.9228012E-01) * X)

F = +9.6999494E-01   SIGNIFICANCE OF F = NOT SIGNIFICANT σ_Y = +1.0659794E+02
R = -8.1798563E-02   SIGNIFICANCE OF R = NOT SIGNIFICANT S_b = +3.9830115E-01
ι = +9.8488321E-01   SIGNIFICANCE OF ι = NOT SIGNIFICANT S_e = +1.0660897E+02
N = 146   DEGREES OF FREEDOM = 144

STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH



TENSILE, MODULUS AT 0.002 IN/MIN, ACRYLIC ACID STUDY

Figure 9

Y = ((+5.2731788E+02) + (+5.3727054E-01) * X)

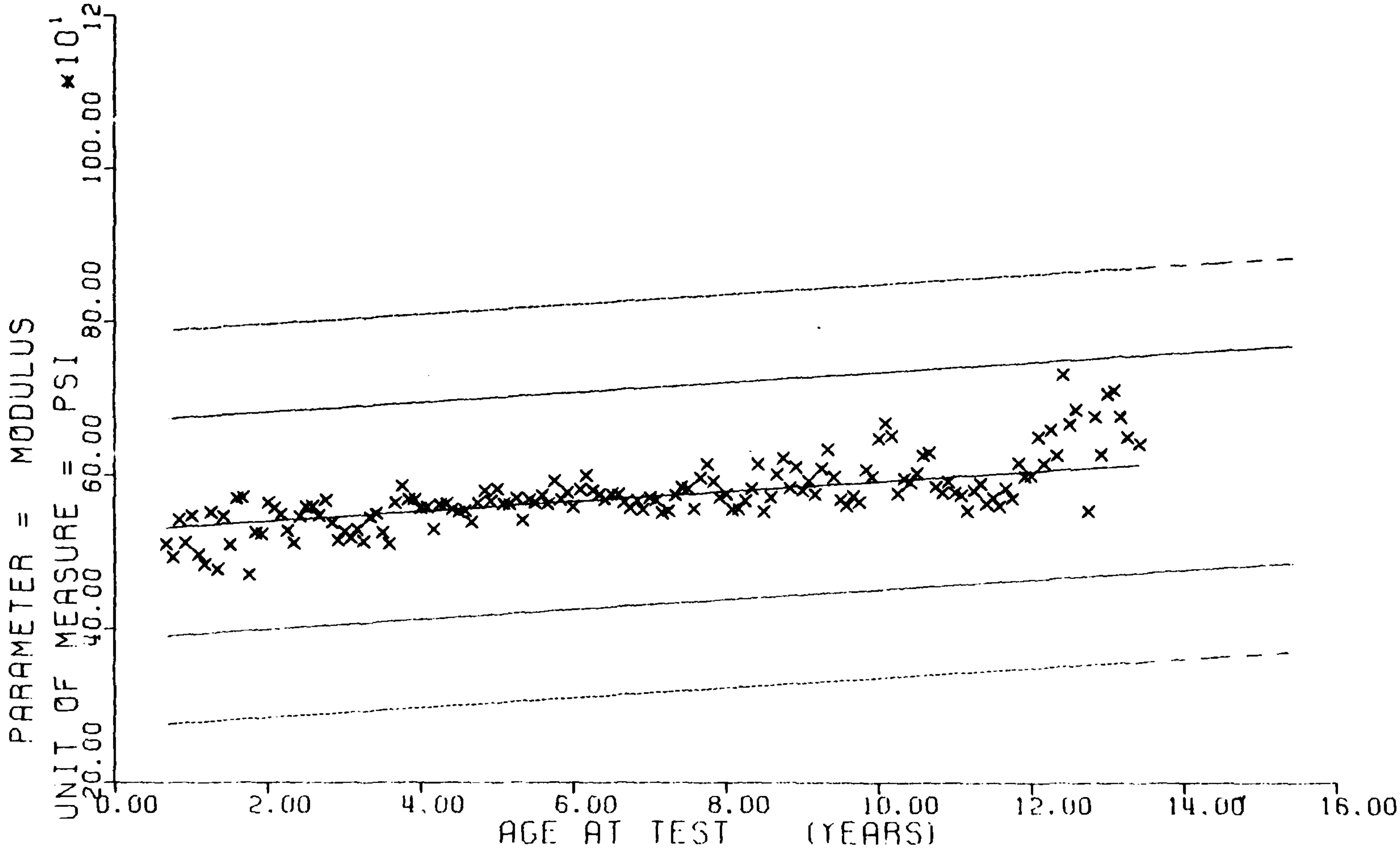
F = +8.4188960E+02 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +8.7437293E+01

R = +2.1044459E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +1.8516779E-02

t = +2.9015334E+01 SIGNIFICANCE OF t = SIGNIFICANT S_E = +8.5481556E+01

N = 18170 DEGREES OF FREEDOM = 18168

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



WING 6,V.L.R.TENSILE,MODULUS,CHS=0.002 IN/MIN TP-H1011

Figure 10

Y = ((+1.1394539E+02) + (+7.0134174E-02) * X)

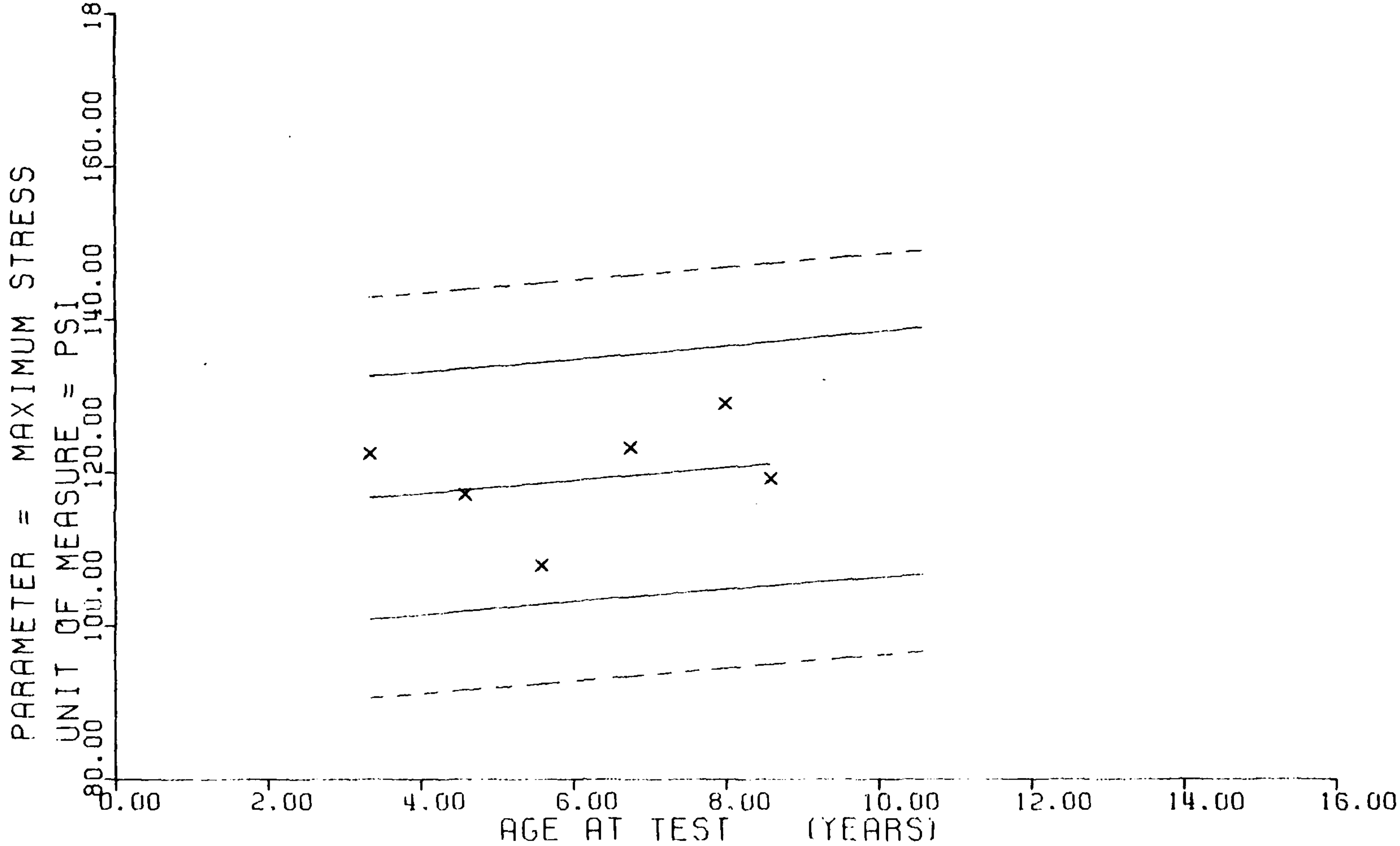
F = +4.1094652E+00 SIGNIFICANCE OF F = NOT SIGNIFICANT σ_1 = +8.8357361E+00

R = +1.8270352E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +3.4596887E-02

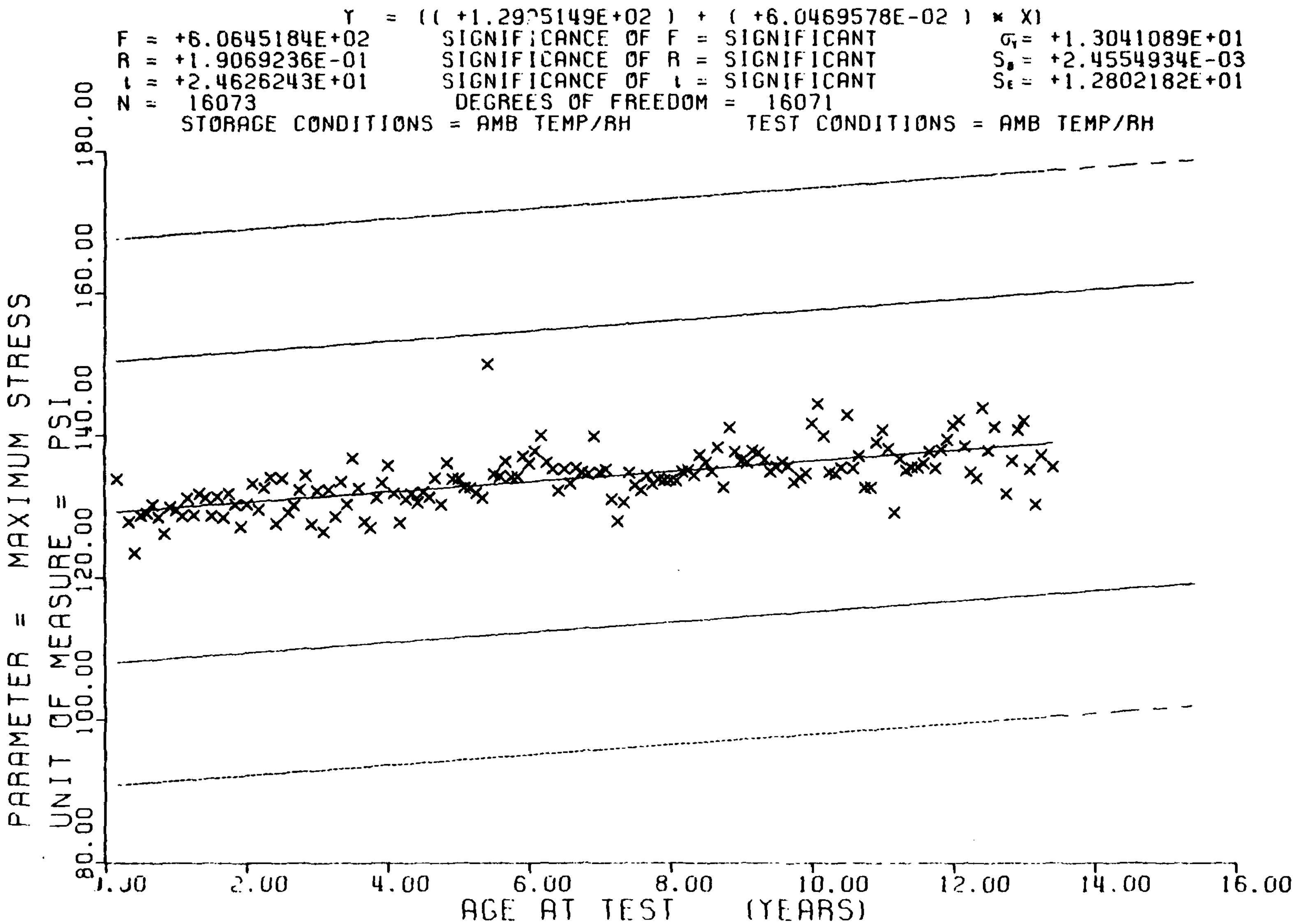
ι = +2.0271816E+00 SIGNIFICANCE OF ι = SIGNIFICANT S_E = +8.7234372E+00

N = 121 DEGREES OF FREEDOM = 119

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



TENSILE, MAXIMUM STRESS, 2.0 IN/MIN, ACRYLIC ACID STUDY



WING G,L.R.TENSILE,MAXIMUM STRESS,CHS=2.0 IN/MIN TP-H1011

Figure 12

Y = ((+8.9133402E+01) + (+2.0759575E-01) * X)

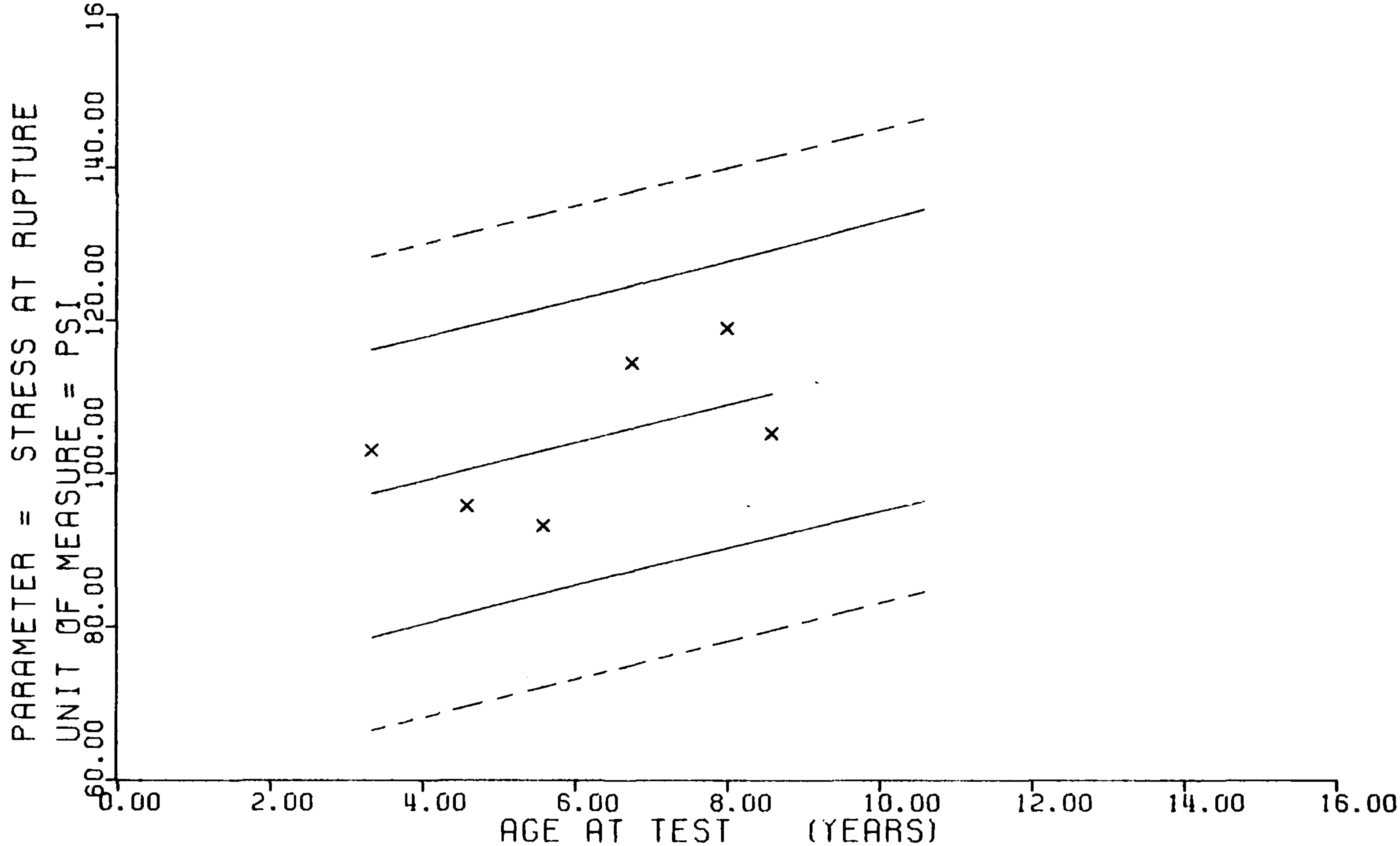
F = +2.5814229E+01 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +1.1317603E+01

R = +4.2220557E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +4.0859108E-02

t = +5.0807705E+00 SIGNIFICANCE OF t = SIGNIFICANT S_E = +1.0302425E+01

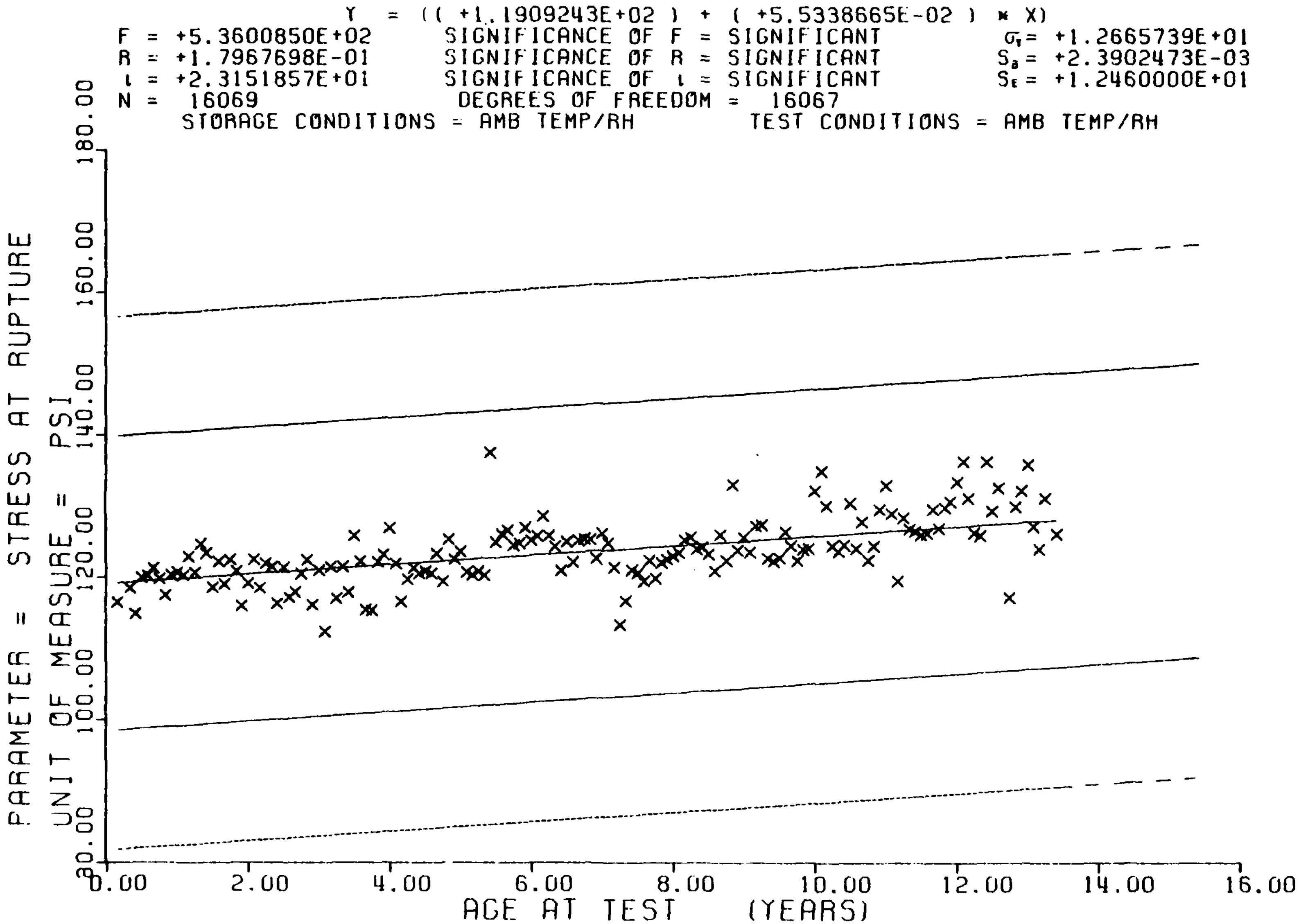
N = 121 DEGREES OF FREEDOM = 119

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



TENSILE, STRESS, AT RUPTURE, 2.0 IN/MIN, ACRYLIC ACID STUDY

Figure 13



WING 6,L.R.TENSILE,STRESS AT RUPTURE,CHS=2.0 IN/MIN TP-H1011

Figure 14

Y = ((+2.7221596E-01) + (-2.4476344E-04) * X)

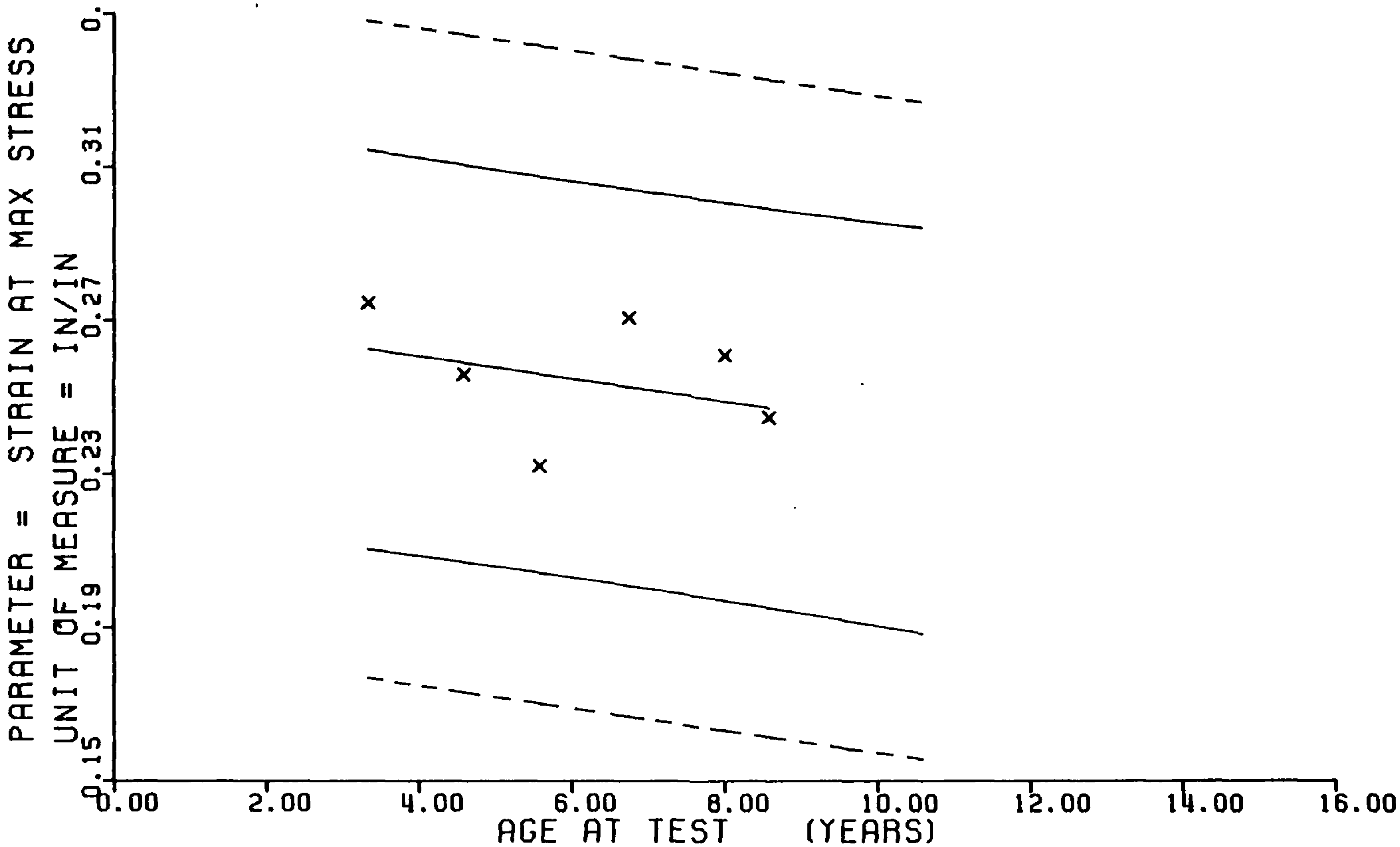
F = +4.6736705E+00 SIGNIFICANCE OF F = NOT SIGNIFICANT σ_Y= +2.8981183E-02

R = -1.9439738E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B= +1.1321852E-04

t = +2.1618673E+00 SIGNIFICANCE OF t = SIGNIFICANT S_E= +2.8547502E-02

N = 121 DEGREES OF FREEDOM = 119

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



TENSILE, STRAIN AT MAXIMUM STRESS, 2.0 IN/MIN, ACRYLIC ACID STUDY

Figure 15

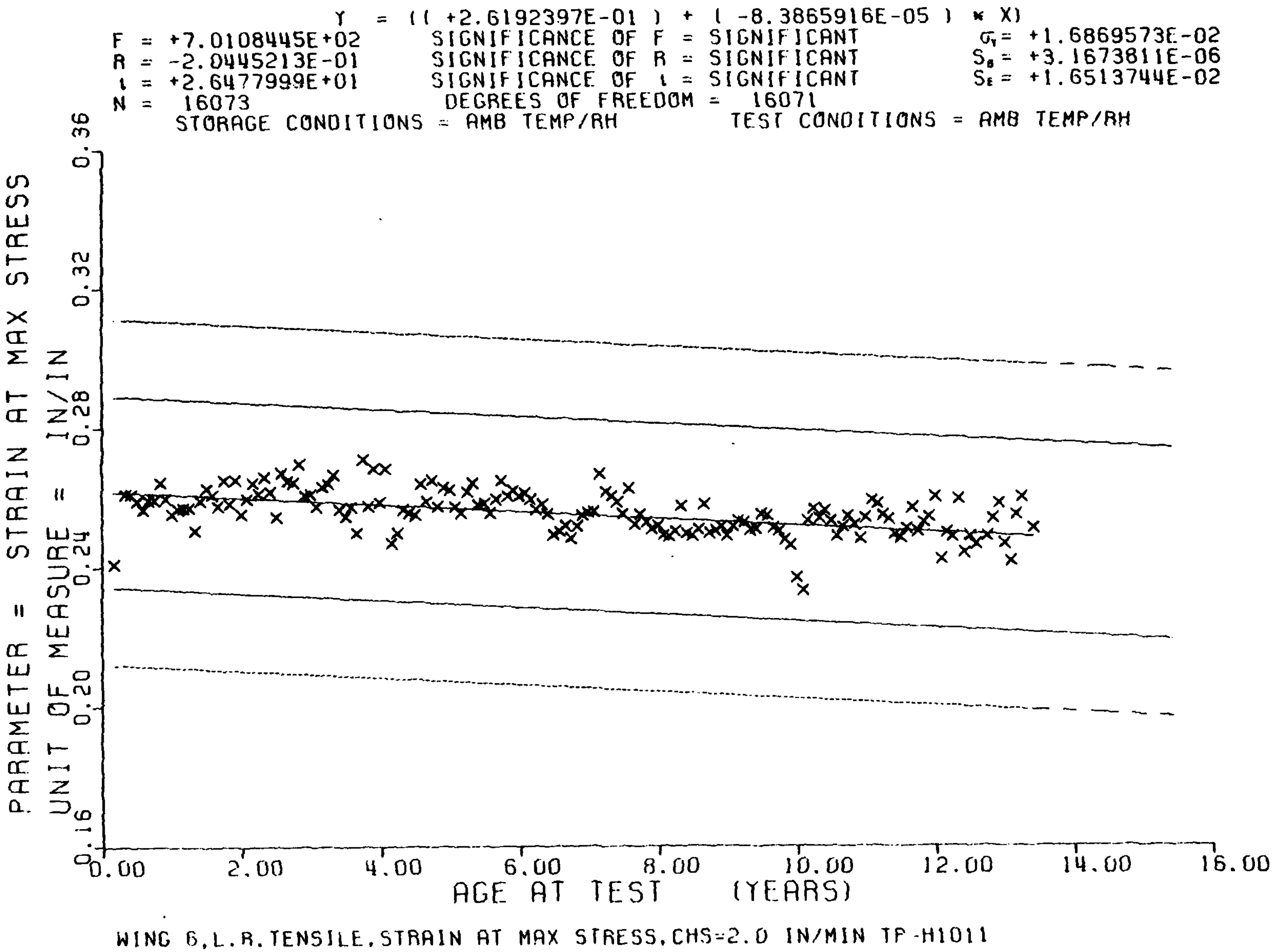

Y = ((+2.6192397E-01) + (-8.3865916E-05) * X)
F = +7.0108445E+02 SIGNIFICANCE OF F = SIGNIFICANT σ = +1.6869573E-02
R = -2.0445213E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +3.1673811E-06
t = +2.6477999E+01 SIGNIFICANCE OF t = SIGNIFICANT S_E = +1.6513744E-02
N = 16073 DEGREES OF FREEDOM = 16071
STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH
PARAMETER = STRAIN AT MAX STRESS
UNIT OF MEASURE = IN/IN
0.36
0.32
0.28
0.24
0.20
0.16
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
AGE AT TEST (YEARS)
WING 6,L.R.TENSILE,STRAIN AT MAX STRESS,CHS=2.0 IN/MIN TP-H1011

Figure 16

Y = ((+3.6588295E-01) + (-3.2042493E-04) * X)

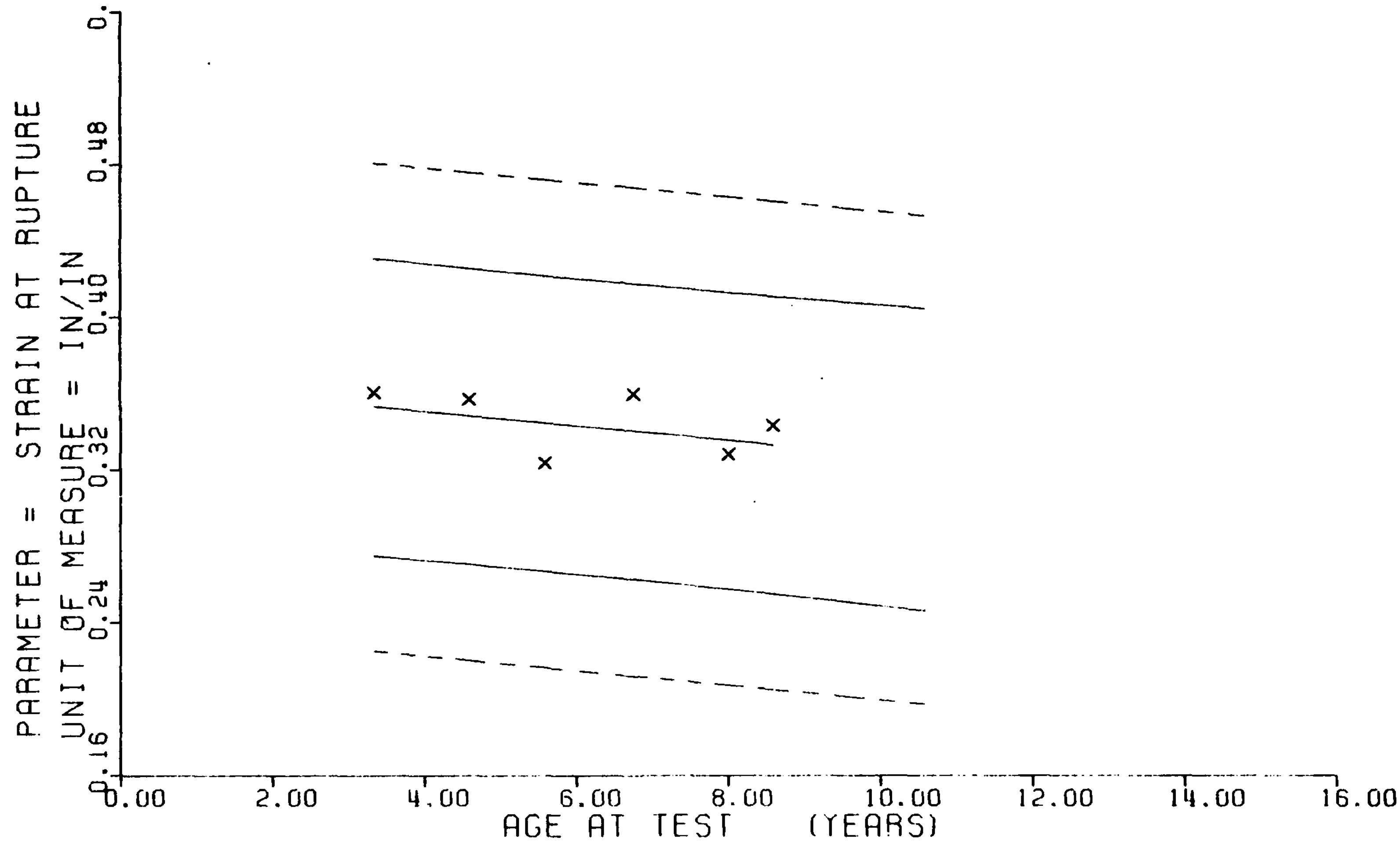
F = +3.5953062E+00   SIGNIFICANCE OF F = NOT SIGNIFICANT σ_Y = +4.3068055E-02

R = -1.7125017E-01   SIGNIFICANCE OF R = NOT SIGNIFICANT S_B = +1.6898896E-04

t = +1.8961292E+00   SIGNIFICANCE OF t = NOT SIGNIFICANT S_E = +4.2609747E-02

N = 121   DEGREES OF FREEDOM = 119

STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH



TENSILE, STRAIN AT RUPTURE, 2.0 IN/MIN, ACRYLIC ACID STUDY

Figure 17

Y = ((+3.2586479E-01) + (-1.9343312E-04) * X)

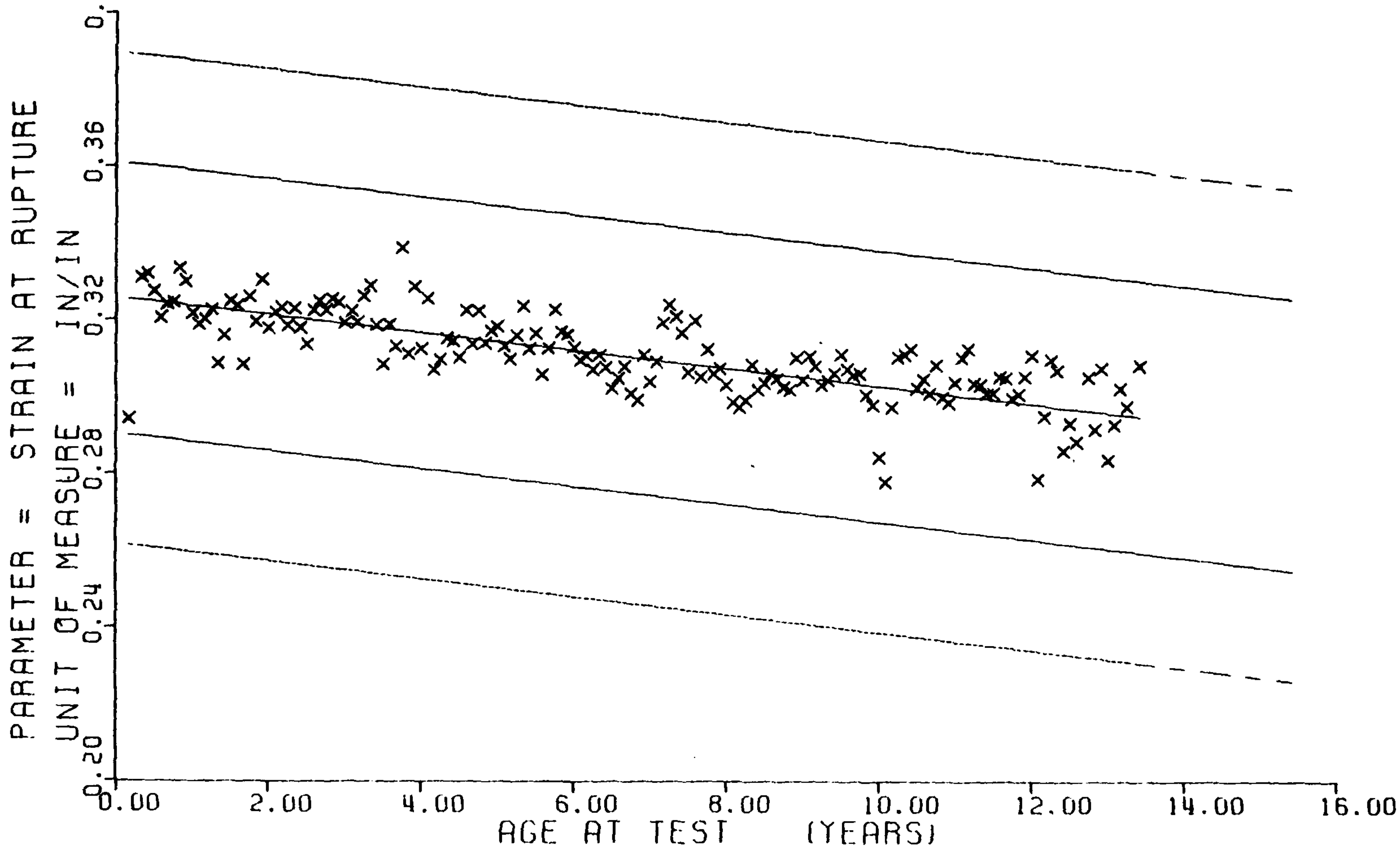
F = +2.2352052E+03   SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +2.2762340E-02

R = -3.4945811E-01   SIGNIFICANCE OF R = SIGNIFICANT S_B = +4.0914018E-06

t = +4.7277957E+01   SIGNIFICANCE OF t = SIGNIFICANT S_E = +2.1327884E-02

N = 16070   DEGREES OF FREEDOM = 16068

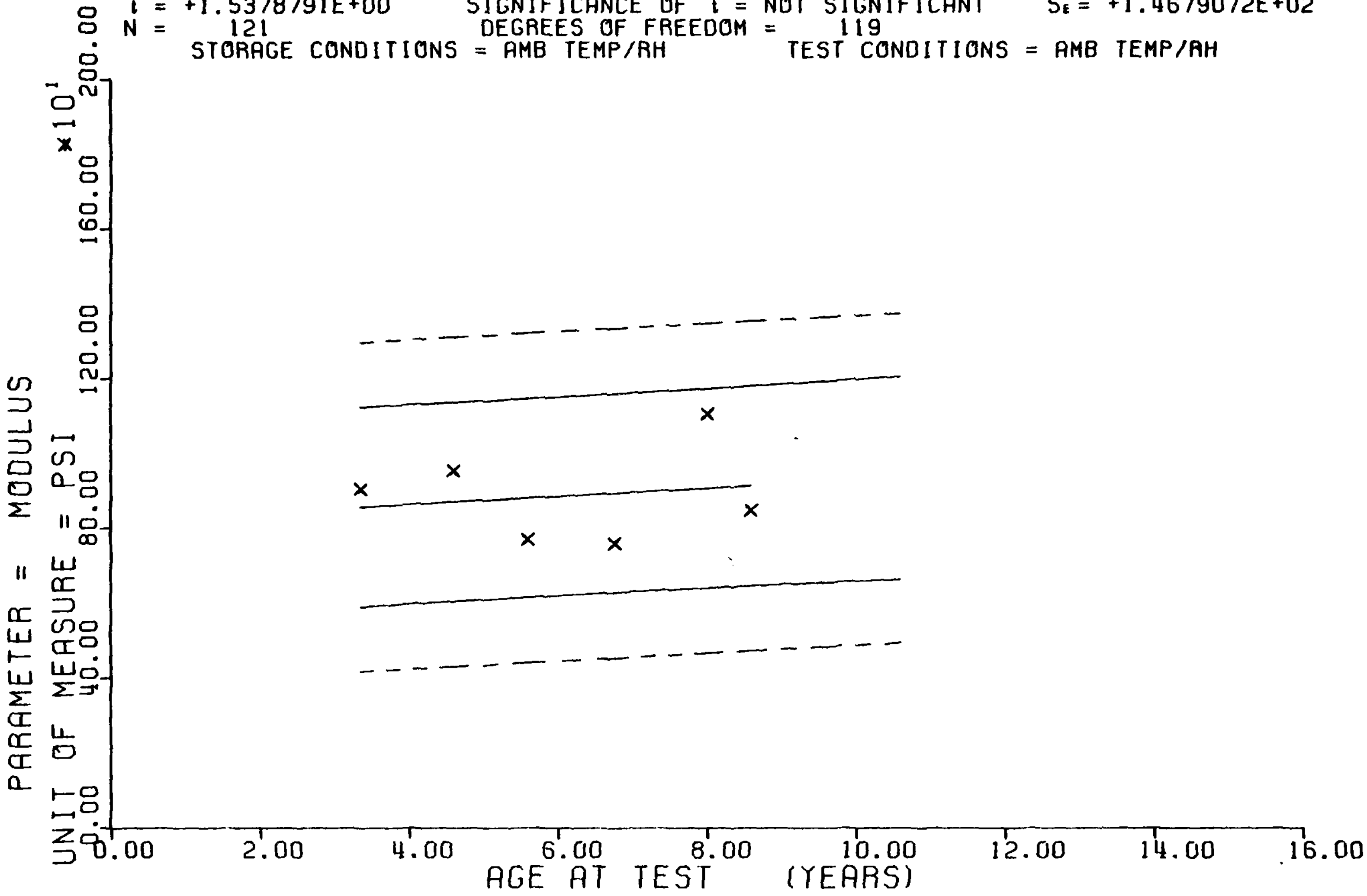
STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH



WING G.L.R. TENSILE, STRAIN AT RUPTURE, CHS=2.0 IN/MIN TP-H1011

Figure 18

Y = ((+8.2129809E+02) + (+8.9530339E-01) * X)
F = +2.3650723E+00 SIGNIFICANCE OF F = NOT SIGNIFICANT σ_Y = +1.4762328E+02
R = +1.3959676E-01 SIGNIFICANCE OF R = NOT SIGNIFICANT S_B = +5.8216757E-01
t = +1.5378791E+00 SIGNIFICANCE OF t = NOT SIGNIFICANT S_E = +1.4679072E+02
N = 121 DEGREES OF FREEDOM = 119
STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



TENSILE, MODULUS AT 2.0 IN/MIN, ACRYLIC ACID STUDY

Figure 19

Y = ((+9.3583772E+02) + (+1.0563893E+00) * X)

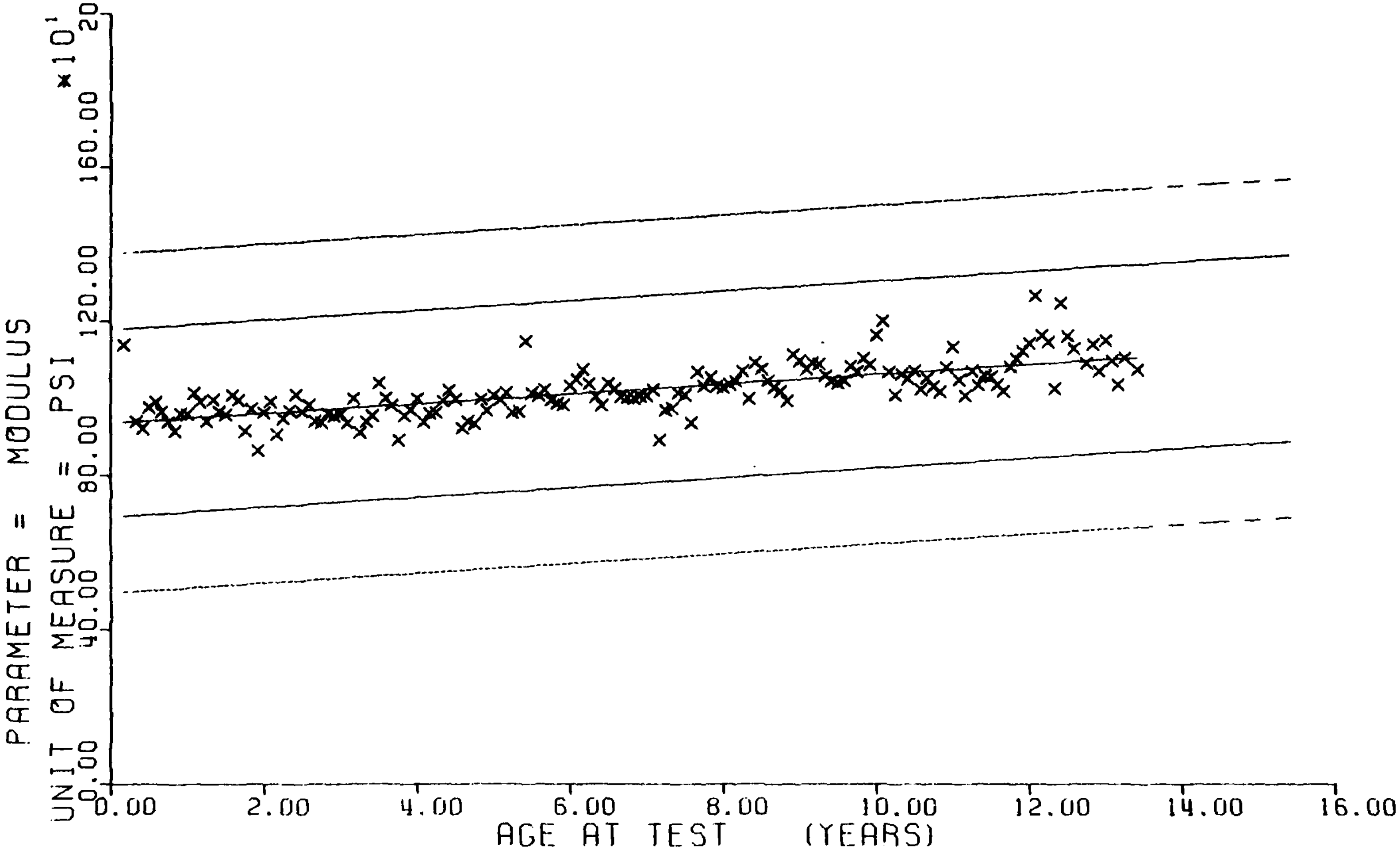
F = +1.4098657E+03 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +1.5298084E+02

R = +2.8405785E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +2.8134235E-02

ι = +3.7548178E+01 SIGNIFICANCE OF ι = SIGNIFICANT S_E = +1.4668369E+02

N = 16065 DEGREES OF FREEDOM = 16063

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



WING G,L.R.TENSILE,MODULUS,CHS=2.0 IN/MIN TP-H1011

Figure 20

Y = ((+2.1239572E+02) + (+3.6669331E+00) * X)

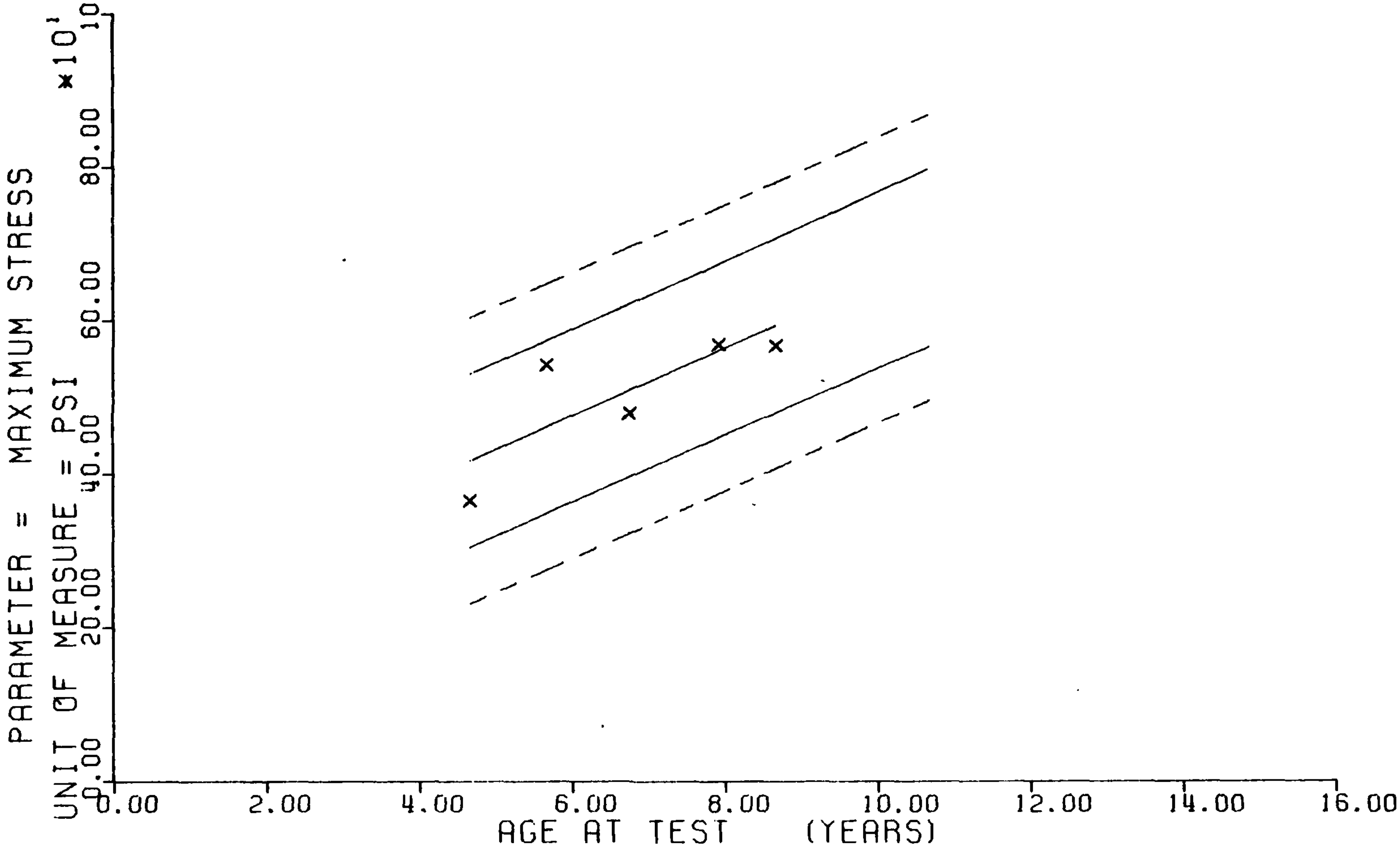
F = +1.3437580E+02 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +9.1448228E+01

R = +7.3702450E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +3.1633150E-01

t = +1.1592057E+01 SIGNIFICANCE OF t = SIGNIFICANT S_E = +6.2079628E+01

N = 115 DEGREES OF FREEDOM = 113

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



HYDROSTATIC TENSILE, MAXIMUM STRESS, 800 PSI, 1750 IN/MIN, ACRYLIC ACID STUDY

Figure 21

Y = ((+4.8437941E+02) + (+5.1048477E-01) * X)

F = +1.2508044E+02 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +1.0110148E+02

R = +1.8033728E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +4.5644461E-02

t = +1.1183937E+01 SIGNIFICANCE OF t = SIGNIFICANT S_E = +9.9457272E+01

N = 3723 DEGREES OF FREEDOM = 3721

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH

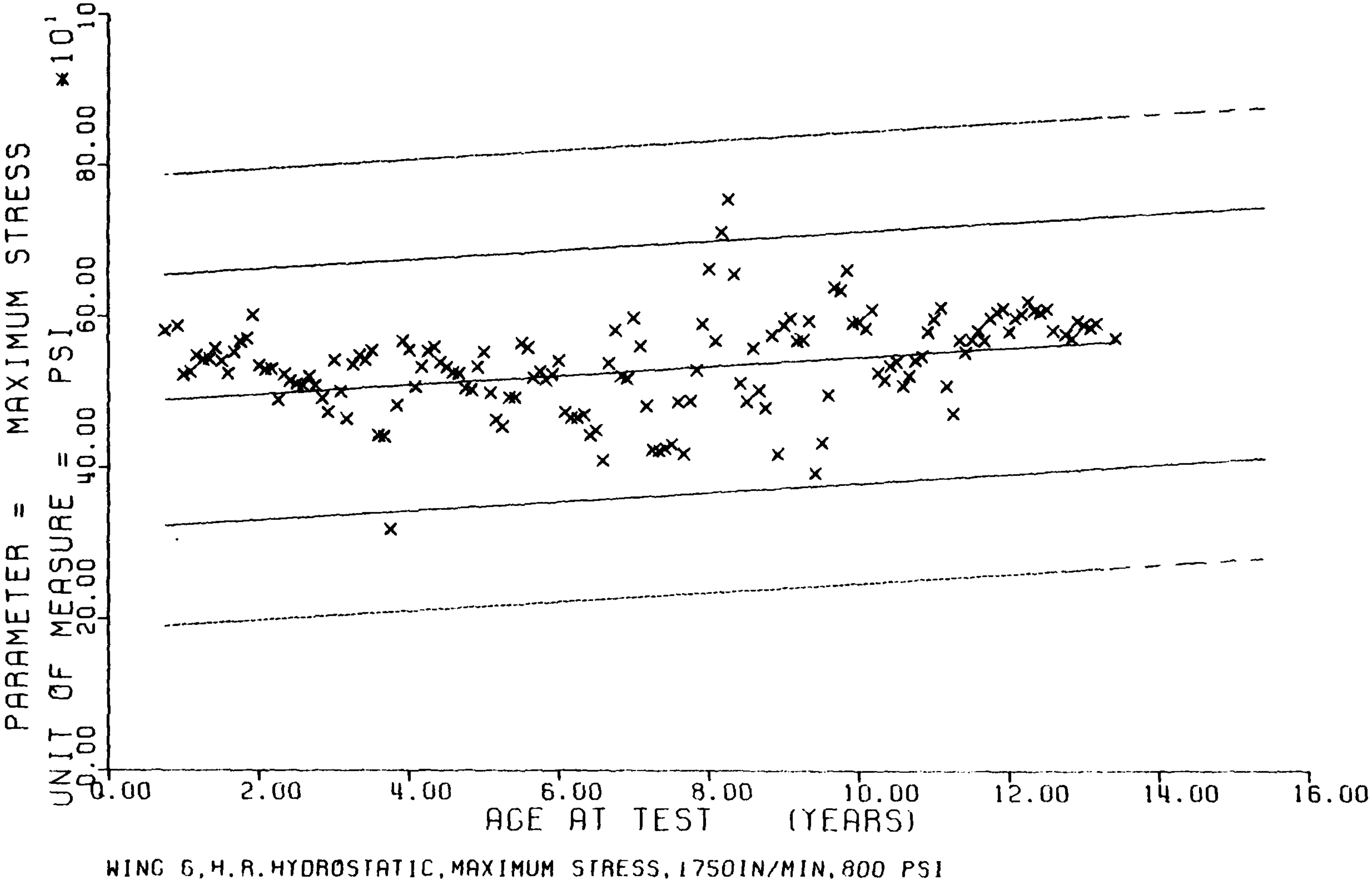
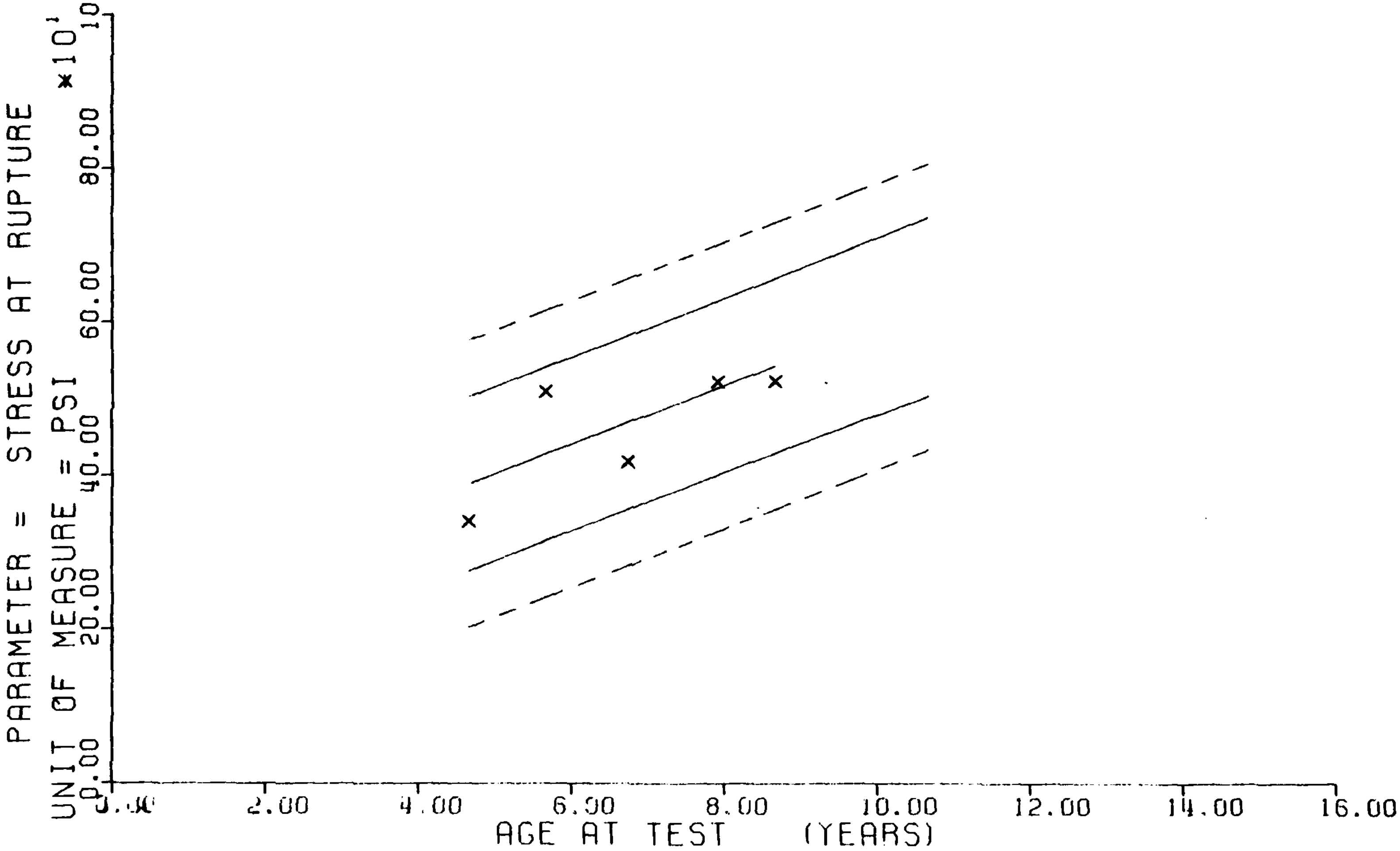


Figure 22

Y = ((+2.1059628E+02) + (+3.1990556E+00) * X)

F = +1.0183537E+02 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +8.5404273E+01
R = +6.8848809E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +3.1700963E-01
t = +1.0091351E+01 SIGNIFICANCE OF t = SIGNIFICANT S_t = +6.2212711E+01
N = 115 DEGREES OF FREEDOM = 113

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = 800 PSI/AMB TEMP



TENSILE, STRESS AT RUPTURE, 800 PSI, 1750 IN/MIN, ACRYLIC ACID STUDY

Figure 23

Y = ((+4.5365280E+02) + (+4.7834763E-01) * X)

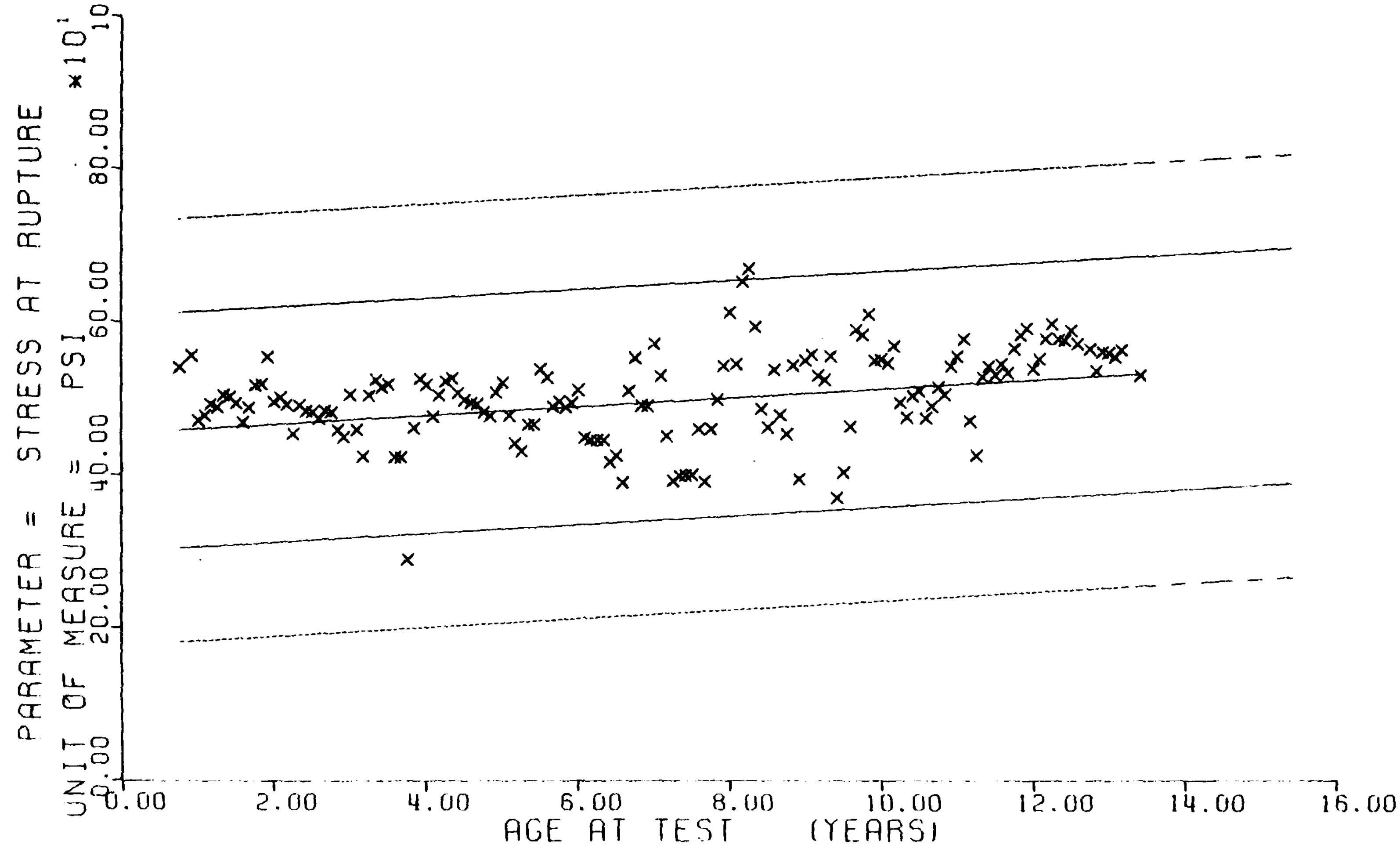
F = +1.2776295E+02 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +9.3769591E+01

R = +1.8219727E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +4.2319561E-02

ι = +1.1303227E+01 SIGNIFICANCE OF ι = SIGNIFICANT S_ι = +9.2212463E+01

N = 3723 DEGREES OF FREEDOM = 3721

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



WING 6,H.R.HYDROSTATIC,STRESS AT RUPTURE,1750IN/MIN,800 PSI

Figure 24

Y = ((+4.2439282E-01) + (-8.8025945E-04) * X)

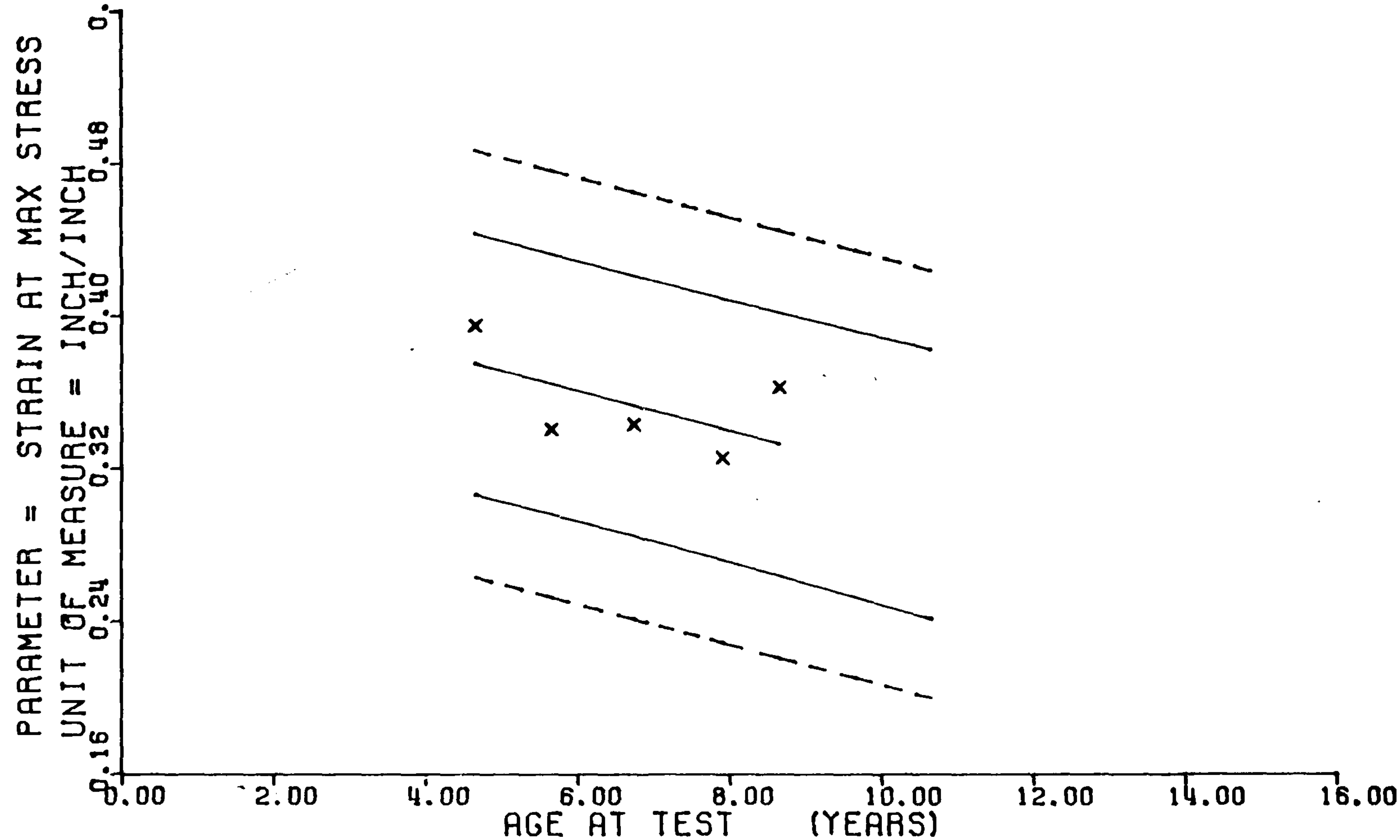
F = +1.9356161E+01 SIGNIFICANCE OF F = SIGNIFICANT σ_y = +4.0335174E-02

R = -3.8985188E-01 SIGNIFICANCE OF R = SIGNIFICANT S_b = +2.0007880E-04

t = +4.3995637E+00 SIGNIFICANCE OF t = SIGNIFICANT S_r = +3.7315323E-02

N = 110 DEGREES OF FREEDOM = 108

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = 800 PSI/AMB TEMP



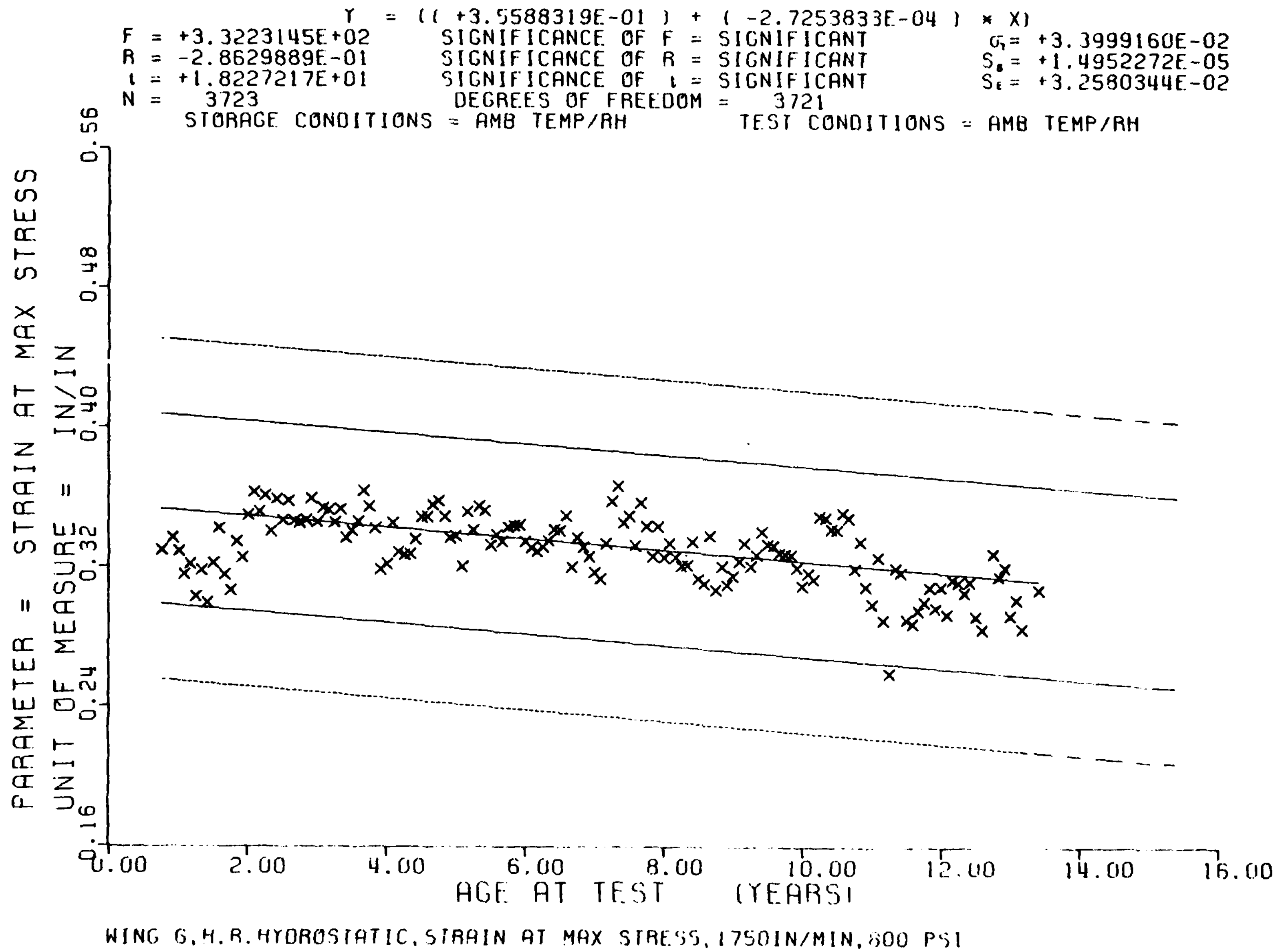
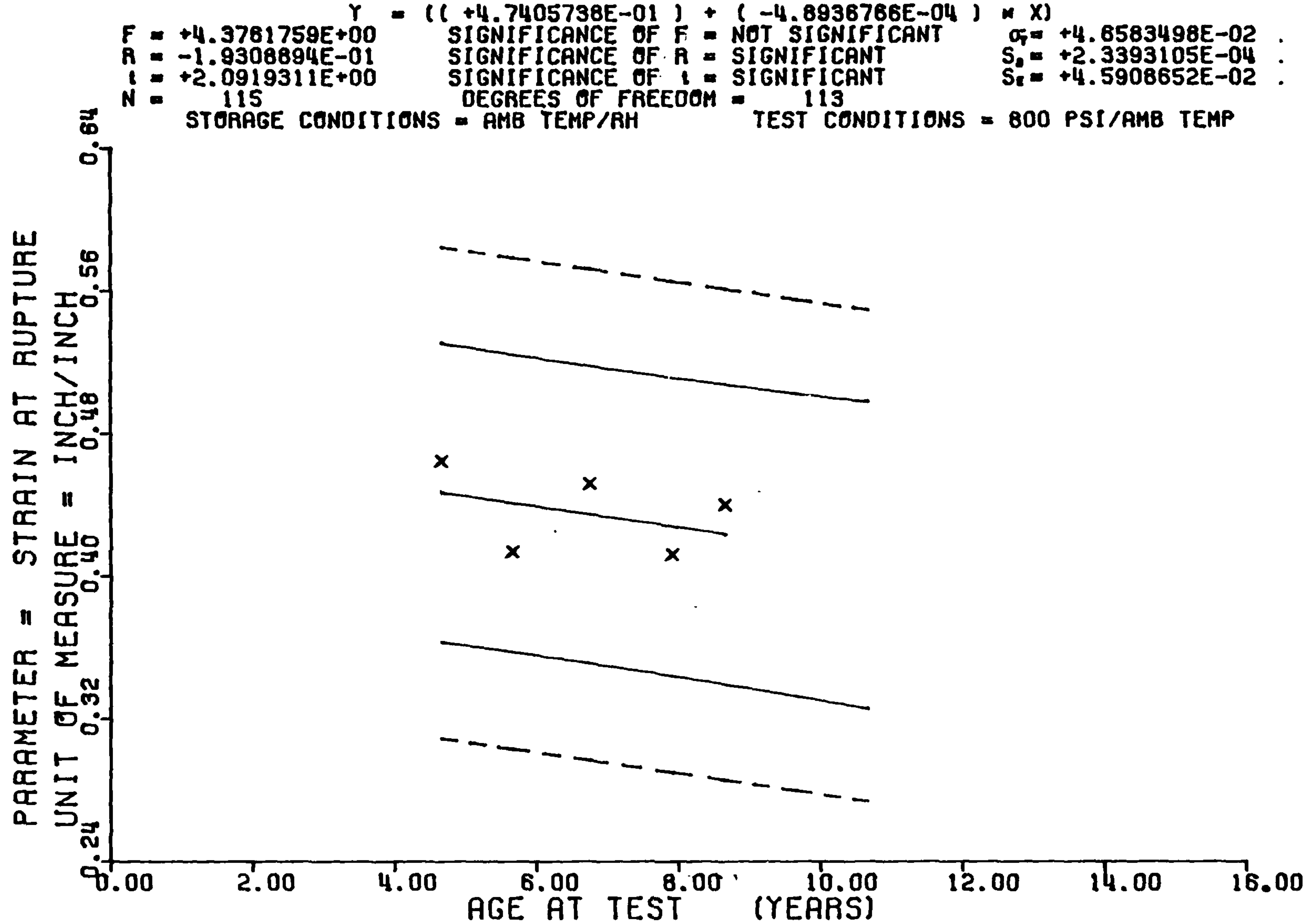

Y = ((+3.5588319E-01) + (-2.7253833E-04) * X)
F = +3.3223145E+02 SIGNIFICANCE OF F = SIGNIFICANT
R = -2.8629889E-01 SIGNIFICANCE OF R = SIGNIFICANT
t = +1.8227217E+01 SIGNIFICANCE OF t = SIGNIFICANT
N = 3723 DEGREES OF FREEDOM = 3721
σ = +3.3999160E-02
S = +1.4952272E-05
S = +3.2580344E-02
STORAGE CONDITIONS = AMB TEMP/RH
TEST CONDITIONS = AMB TEMP/RH
PARAMETER = STRAIN AT MAX STRESS
UNIT OF MEASURE = IN/IN
0.56
0.48
0.40
0.32
0.24
0.16
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
AGE AT TEST (YEARS)
WING G,H.R.HYDROSTATIC,STRAIN AT MAX STRESS,1750IN/MIN,800 PSI

Figure 26



TENSILE, STRAIN AT RUPTURE, 800 PSI, 1750 IN/MIN, ACRYLIC ACID STUDY

Figure 27

Y = ((+4.2480003E-01) + (-2.9508579E-04) * X)

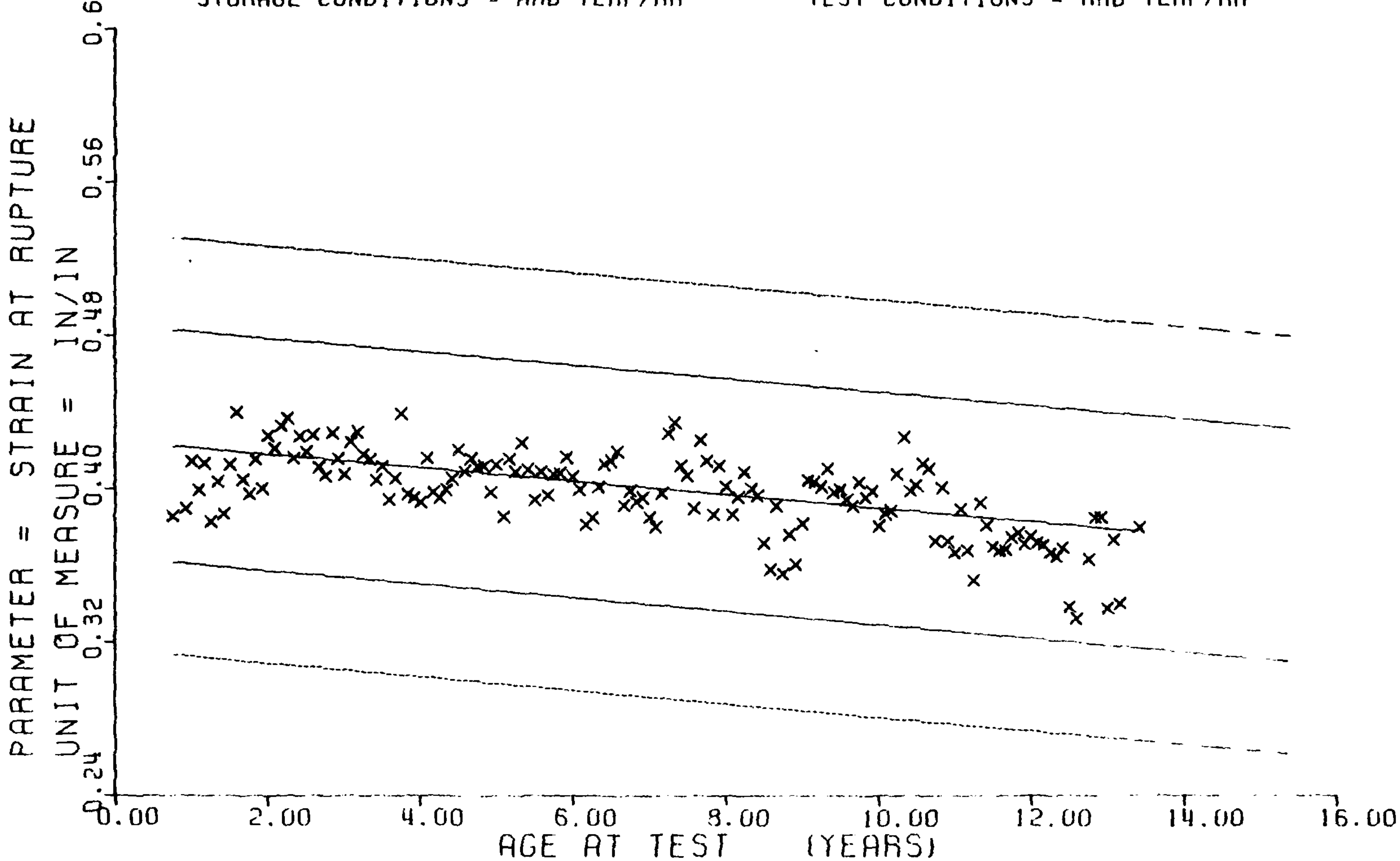
F = +3.1438887E+02 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +3.7741044E-02

R = -2.7918915E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +1.6642352E-05

ι = +1.7731014E+01 SIGNIFICANCE OF ι = SIGNIFICANT S_E = +3.6245186E-02

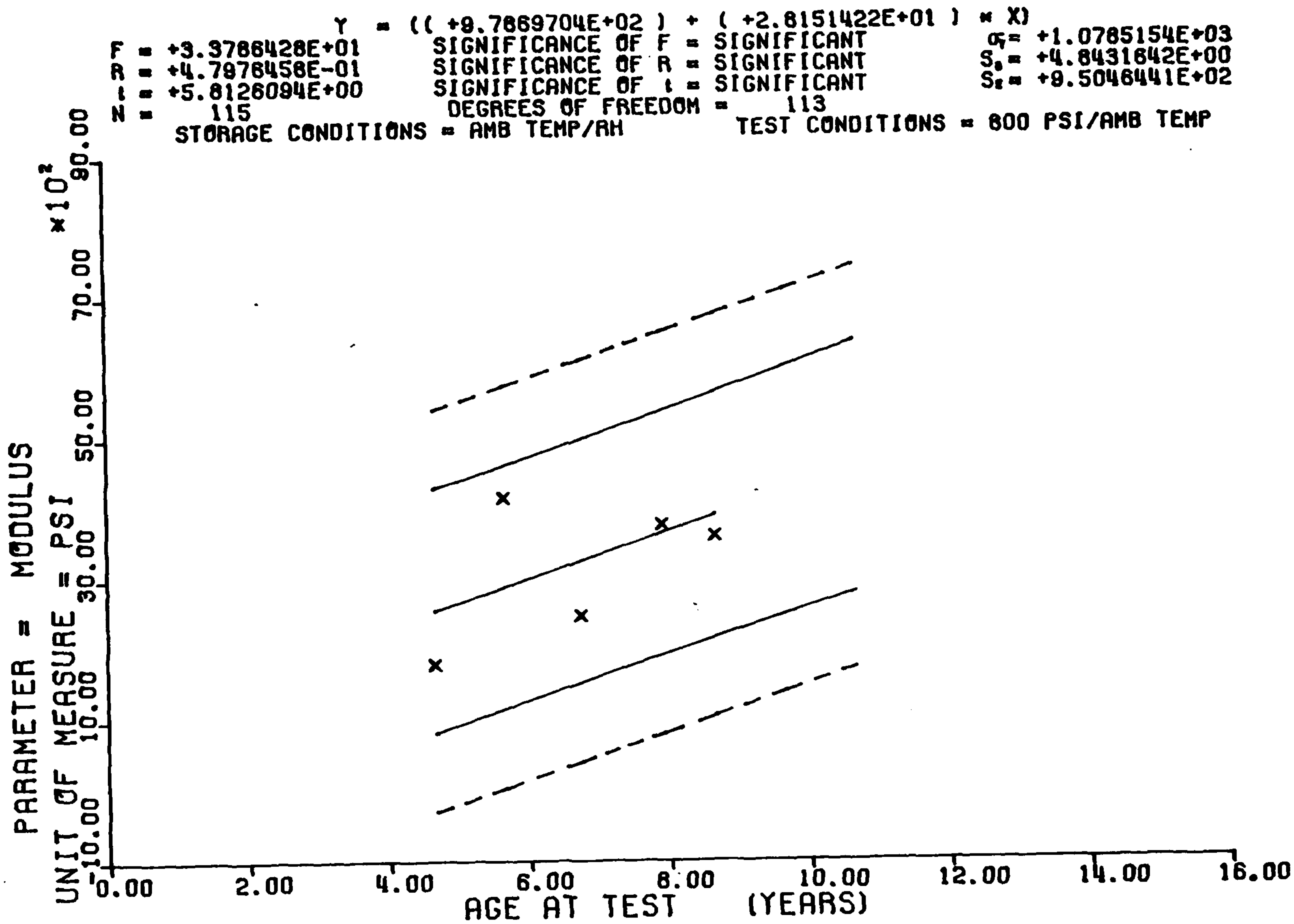
N = 3721 DEGREES OF FREEDOM = 3719

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



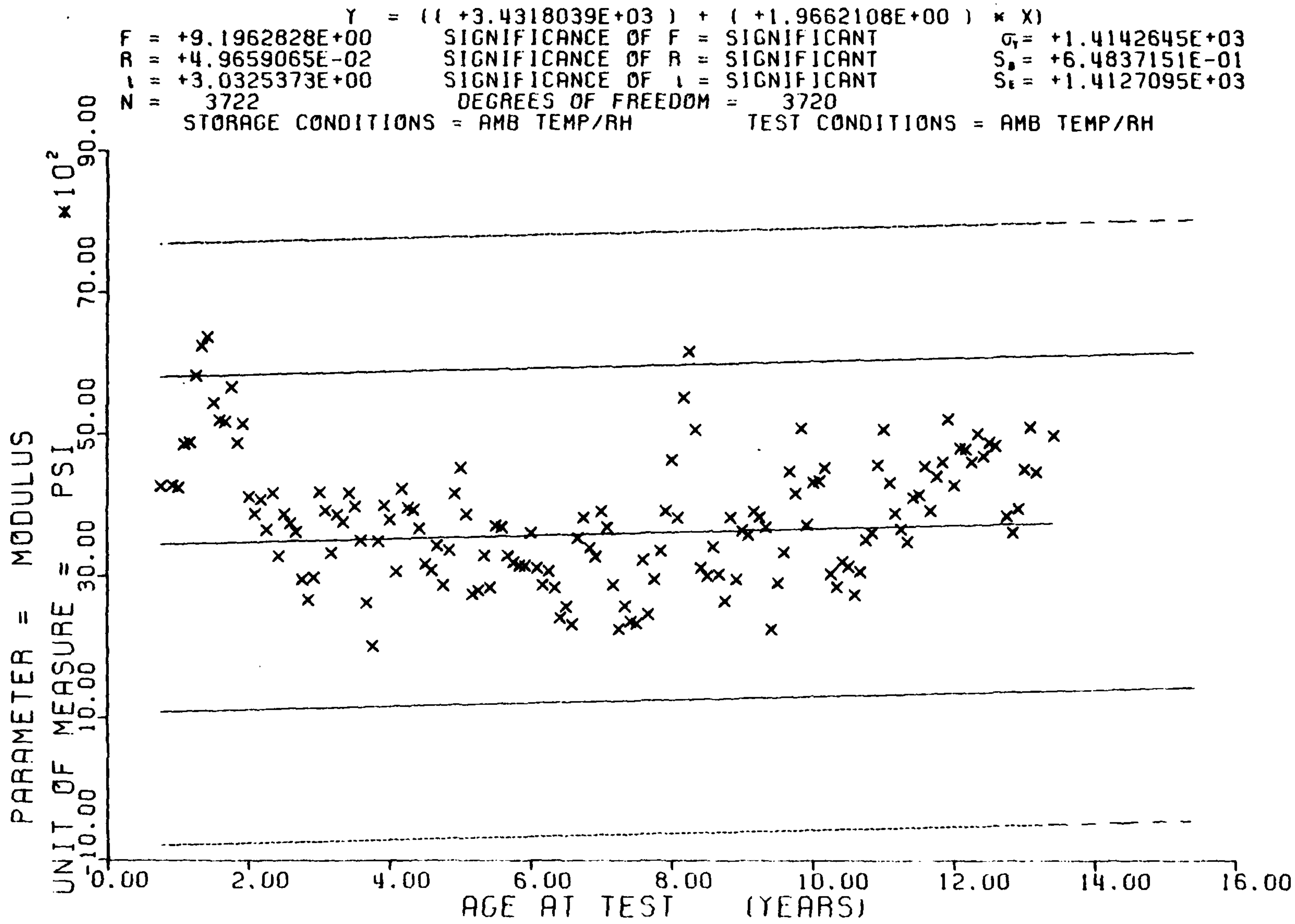
WING 6,H.R.HYDROSTATIC,STRAIN AT RUPTURE,1750IN/MIN,800 PSI

Figure 28



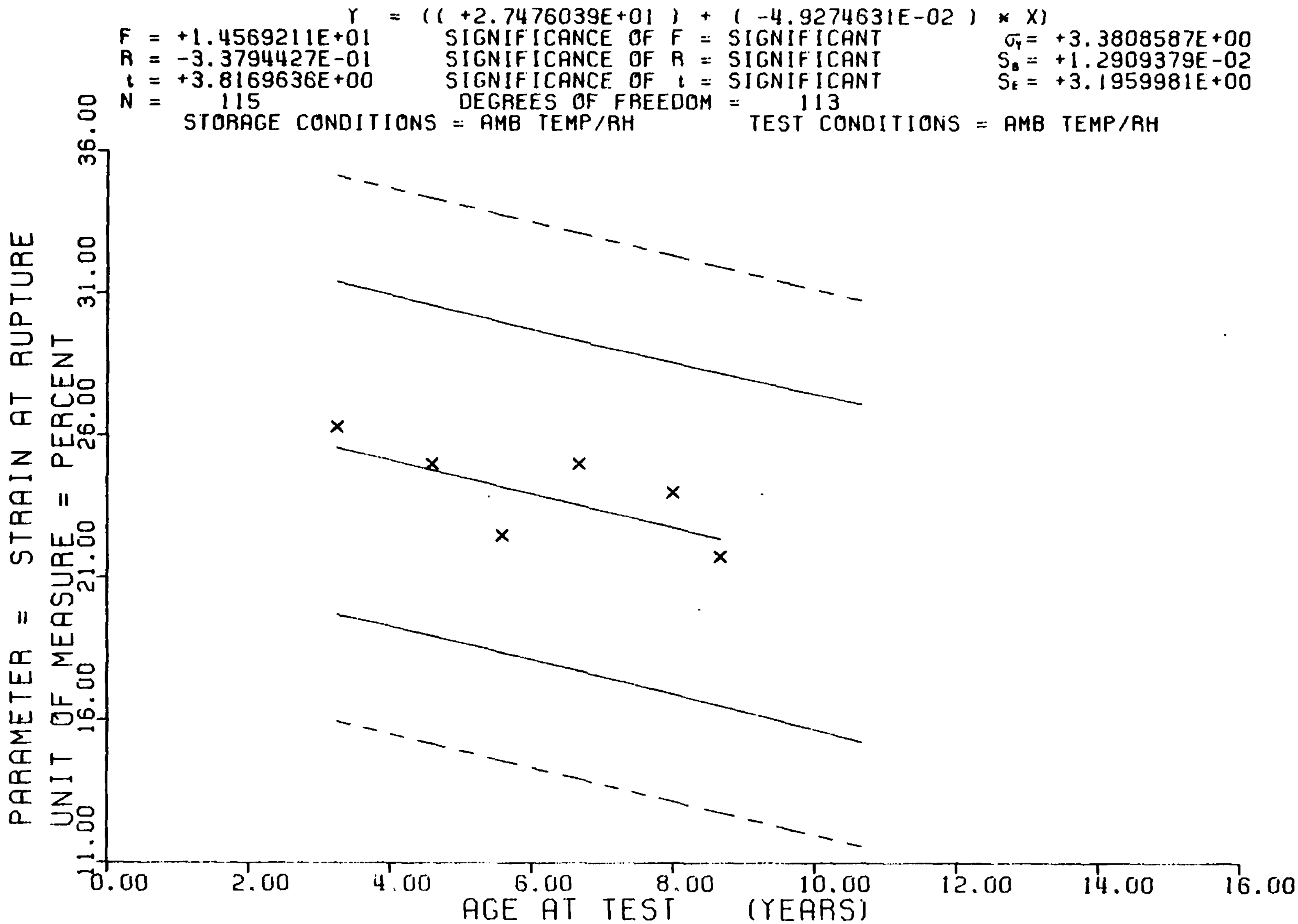
TENSILE, MODULUS, 800 PSI, 1750 IN/MIN, ACRYLIC ACID STUDY

Figure 29



WING 6,H.R.HYDROSTATIC.MODULUS,1750 IN/MIN, 800 PSI

Figure 30



CONSTANT STRAIN, ACRYLIC ACID STUDY

Figure 31

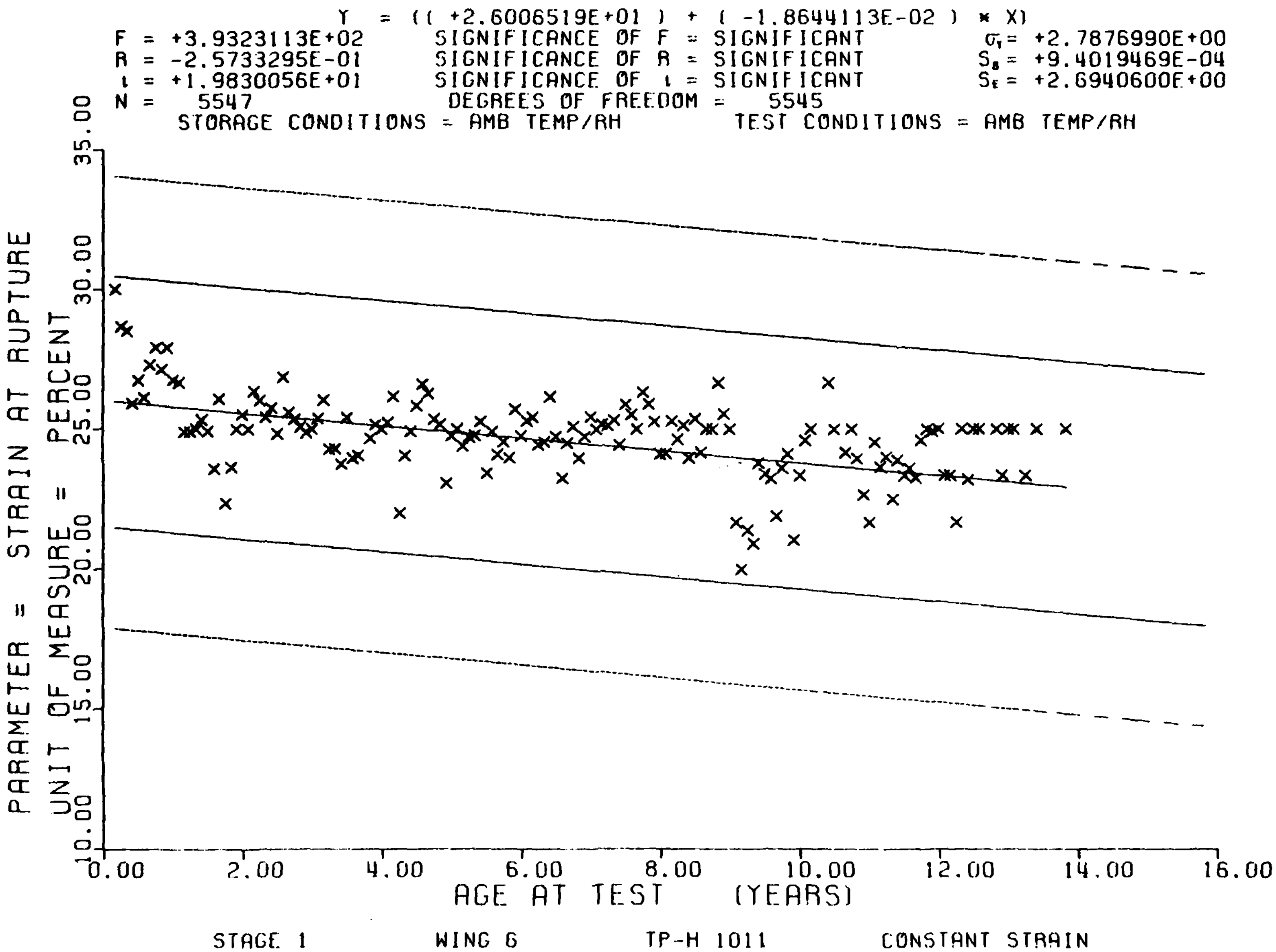
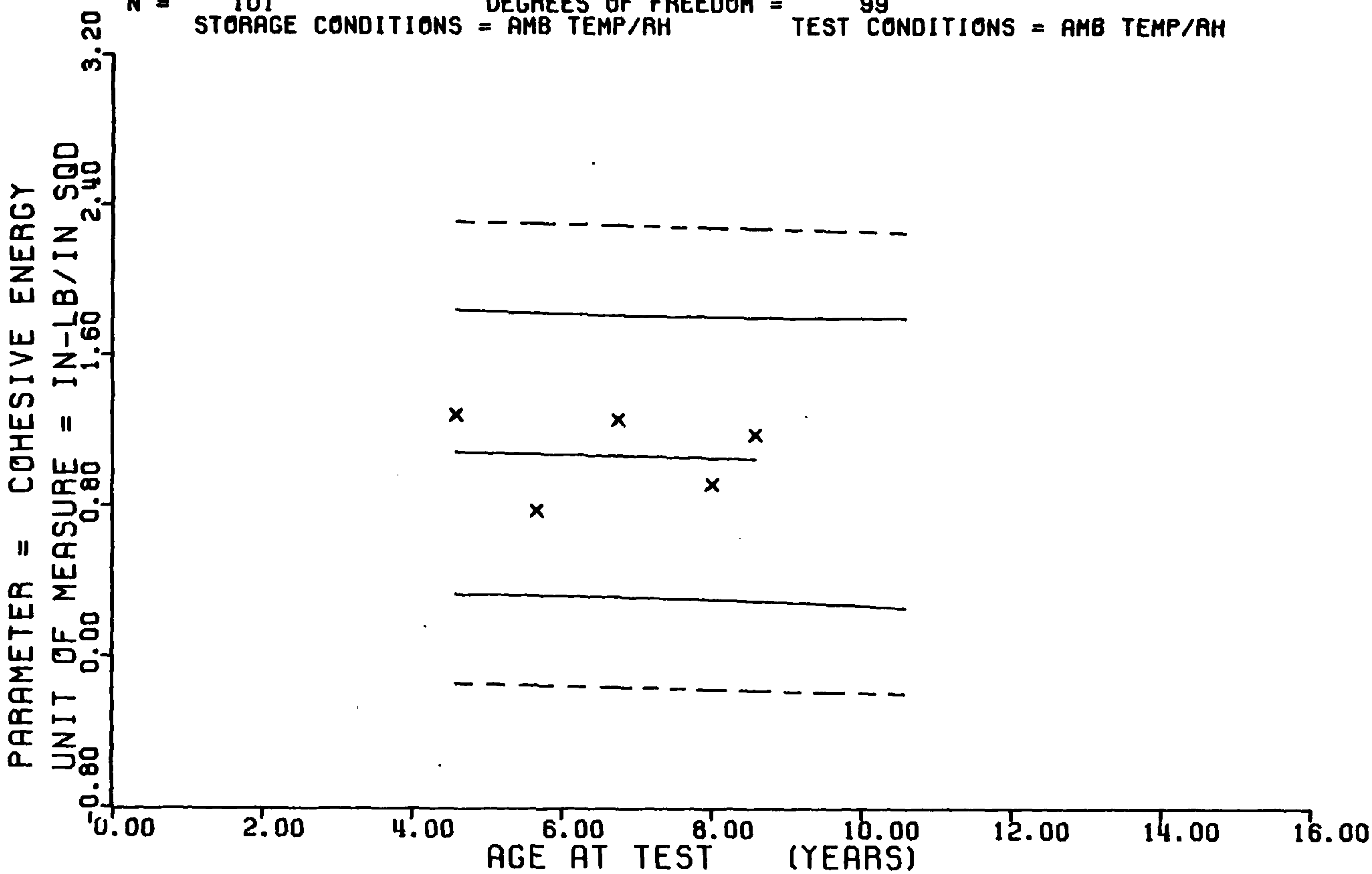

Y = ((+2.6006519E+01) + (-1.8644113E-02) * X)
F = +3.9323113E+02 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +2.7876990E+00
R = -2.5733295E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +9.4019469E-04
t = +1.9830056E+01 SIGNIFICANCE OF t = SIGNIFICANT S_E = +2.6940600E+00
N = 5547 DEGREES OF FREEDOM = 5545
STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH
PARAMETER = STRAIN AT RUPTURE
UNIT OF MEASURE = PERCENT
35.00
30.00
25.00
20.00
15.00
10.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
AGE AT TEST (YEARS)
STAGE 1
WING 6
TP-H 1011
CONSTANT STRAIN

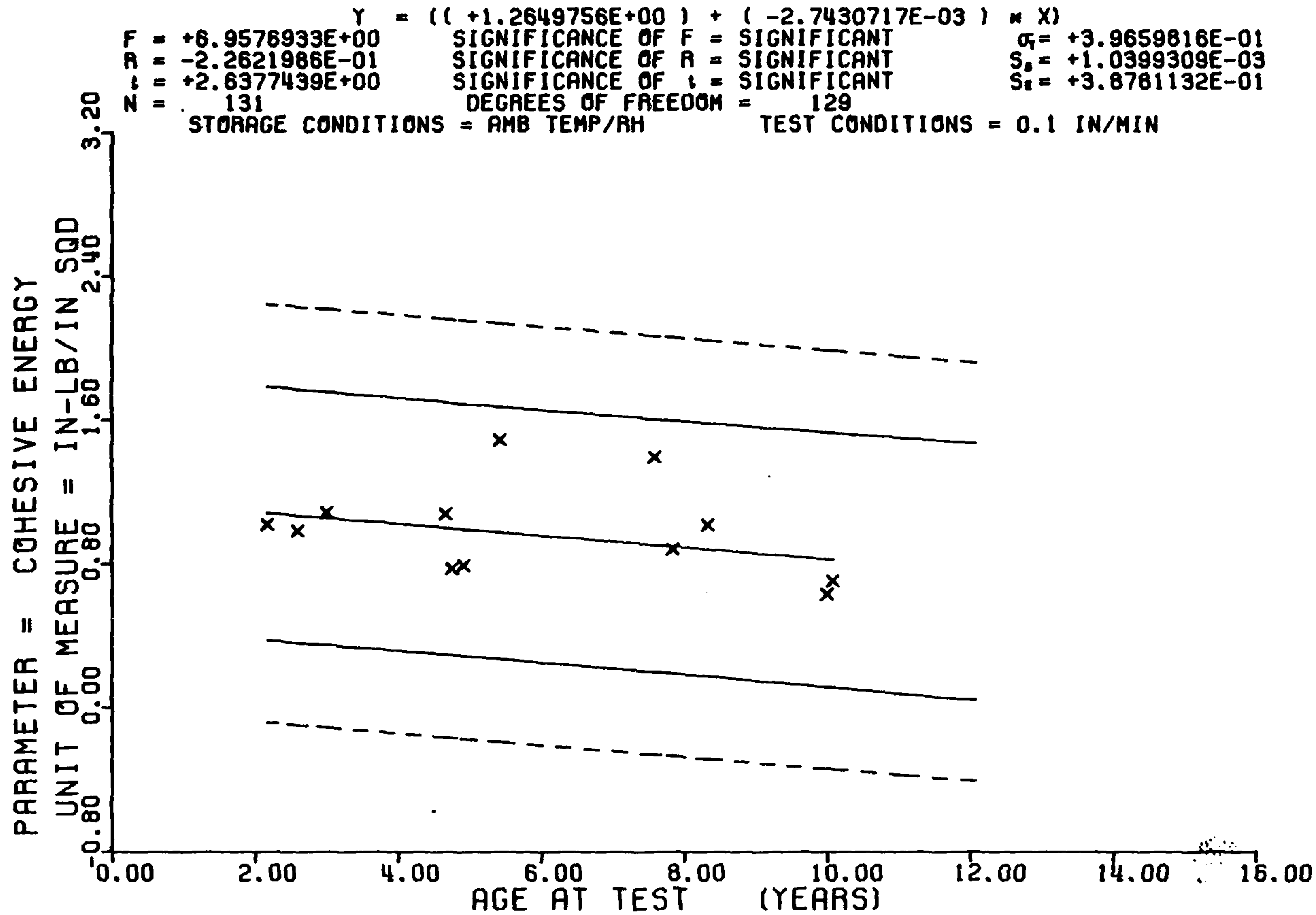
Figure 32

```
                    Y  =  (( +1.1323903E+00 ) + ( -7.9736920E-04 ) * X)
F = +1.2907925E-01     SIGNIF'CANCE OF F = NOT SIGNIFICANT     σ = +4.0742098E-01
R = -3.6085081E-02     SIGNIFICANCE OF R = NOT SIGNIFICANT     S = +2.2193777E-03
t = +3.5927601E-01     SIGNIFICANCE OF t = NOT SIGNIFICANT     S = +4.0920681E-01
N =    101              DEGREES OF FREEDOM =     99
    STORAGE CONDITIONS = AMB TEMP/RH          TEST CONDITIONS = AMB TEMP/RH
```



TEAR ENERGY, COHESIVE ENERGY AT 0.1 IN/MIN, ACRYLIC ACID STUDY

Figure 33



TEAR ENERGY, COHESIVE ENERGY AT 0.1 IN/MIN, STAGE 1, WING 6 (F&G)

Figure 34

Y = ((+2.3448486E+00) + (+6.1384488E-01) * X)

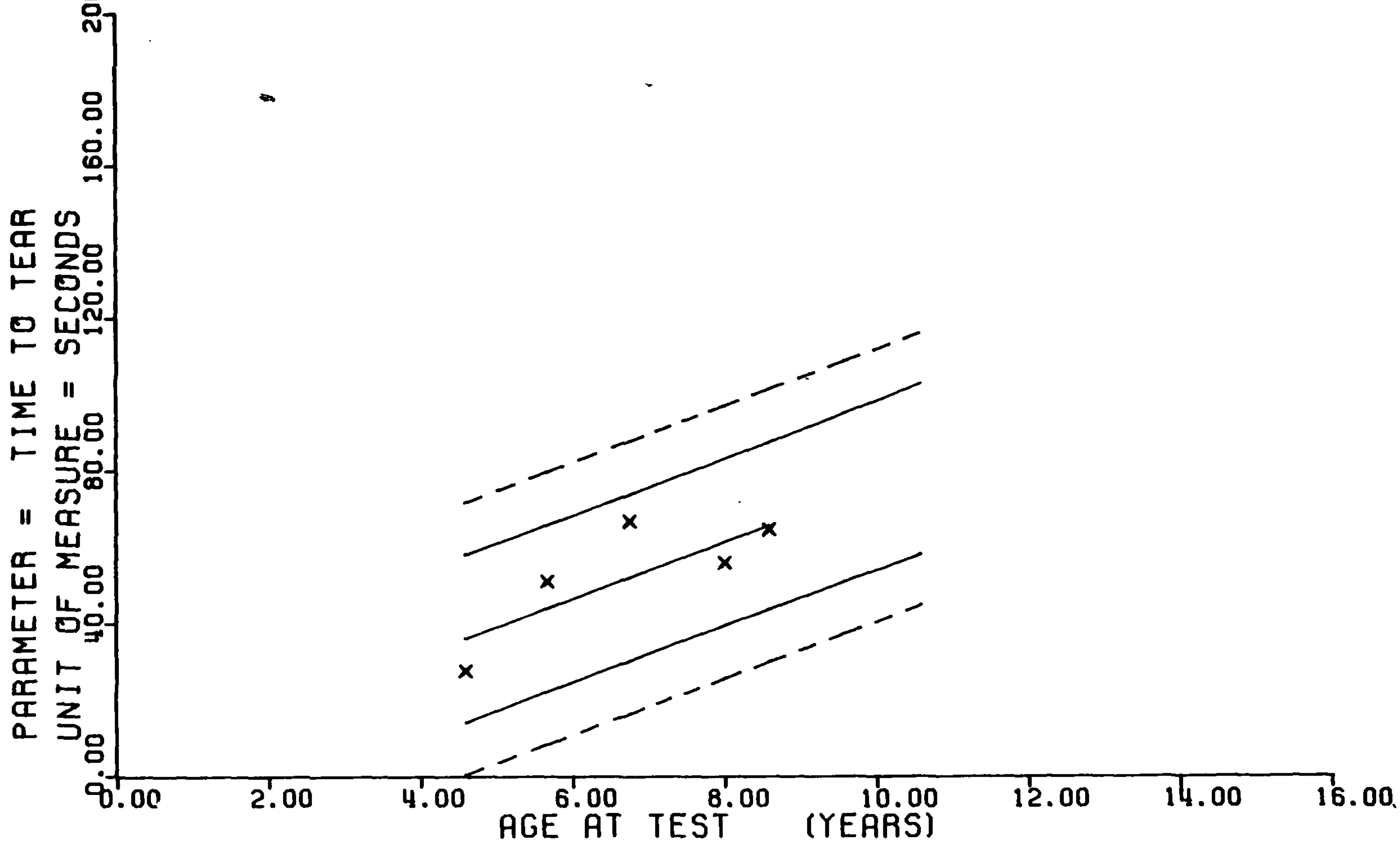
F = +9.0878930E+01 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +1.6359765E+01

R = +6.9162016E-01 SIGNIFICANCE OF R = SIGNIFICANT S_b = +6.4391277E-02

t = +9.5330441E+00 SIGNIFICANCE OF t = SIGNIFICANT S_E = +1.1872404E+01

N = 101 DEGREES OF FREEDOM = 99

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = AMB TEMP/RH



TEAR ENERGY, TIME TO TEAR AT 0.1 IN/MIN, ACRYLIC ACID STUDY

Figure 35

Y = ((+5.9458688E+01) + (-5.0559833E-02) * X)

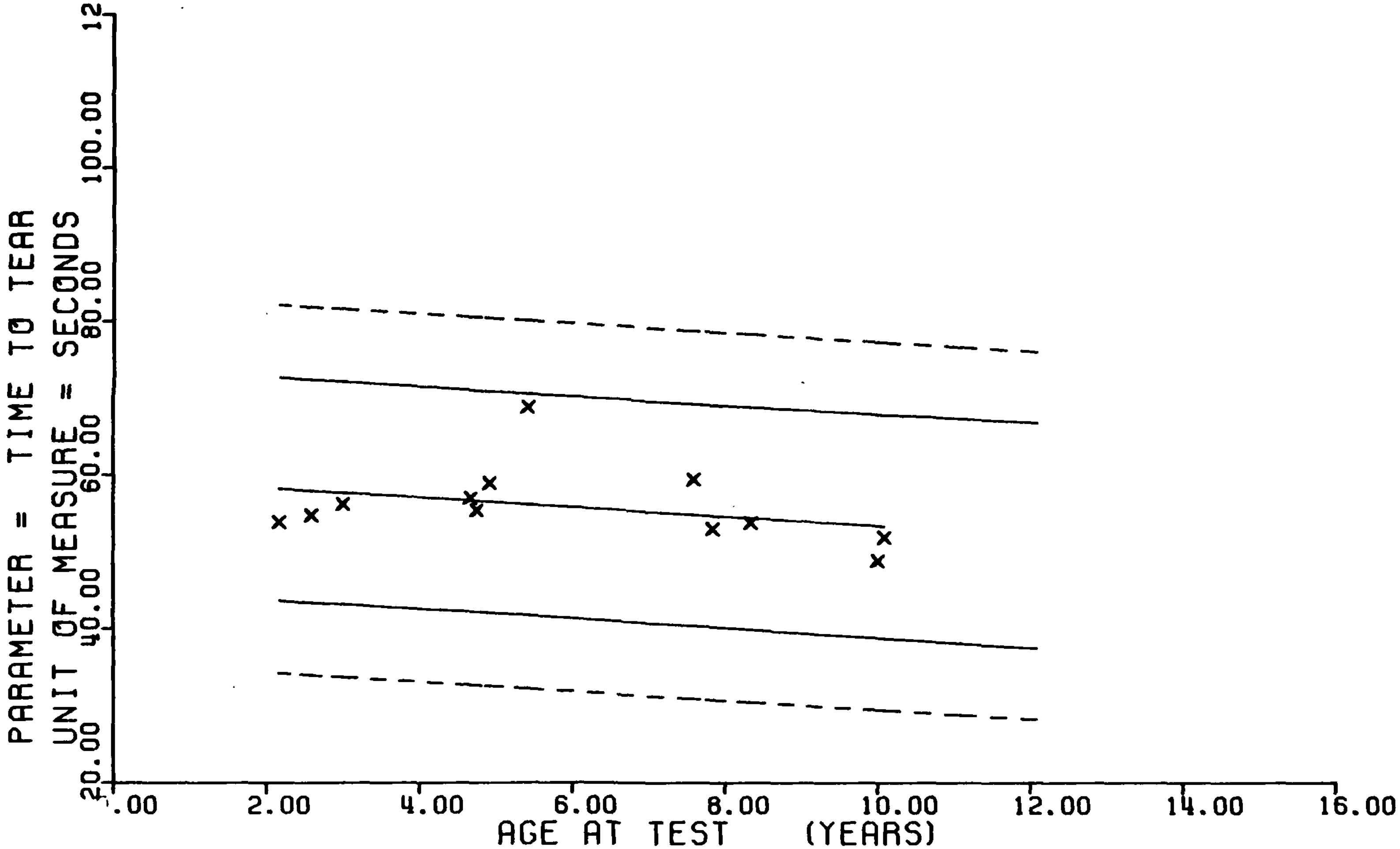
F = +5.5836707E+00 SIGNIFICANCE OF F = SIGNIFICANT σ_Y = +8.1186945E+00

R = -2.0368719E-01 SIGNIFICANCE OF R = SIGNIFICANT S_B = +2.1396647E-02

t = +2.3629792E+00 SIGNIFICANCE OF t = SIGNIFICANT S_E = +7.9792430E+00

N = 131 DEGREES OF FREEDOM = 129

STORAGE CONDITIONS = AMB TEMP/RH TEST CONDITIONS = 0.1 IN/MIN



TEAR ENERGY, TIME TO TEAR AT 0.1 IN/MIN, STAGE 1, WING 6 (F&G)

Figure 36

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Glacial Acrylic Acid
Minuteman

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thiokol Minuteman First Stage Propellant uses acrylic acid to produce the HB polymer used as the binder. The original supplier of acrylic acid stopped production and Thiokol then obtained acrylic acid produced by the Taft, Louisiana Plant of Union Carbide Company.

To assure that this new source of supply was a satisfactory replacement, Thiokol* ran qualifications testing on the new material and found it satisfactory. In the Thiokol* program two motors were cast in 1971 and propellant from the

mixes were cast into cartons for a ten year test program. This propellant was then transferred to this laboratory and testing on a yearly basis was started in 1975.

From an analysis of the data the propellant's physical properties are satisfactory and the stability, with respect to age, is satisfactory.

*Final report evaluation of HB polymer manufactured using Taft glacial acrylic acid. Report number TWR-4716, May 1972. Thiokol/Wasatch Division a division of Thiokol Chemical Corporation.

LME